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INSECTS

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INSECTS

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PREFACE

When I was invited to write a volume on Insects, I was told that it was to be "a general introduction for the thoughtful general student, deep but not too difficult, nutritious but not heavy, unconventional, not primer-like, mainly from the biological side." I have done my best to carry out these instructions, but with such a large field, so full of material, it has been very difficult to make a judicious selection.

Where possible, I have given references to text-books and papers dealing more fully with special points and, in many cases, the works referred to will be found to contain bibliographies on the special part of the subject with which the paper deals. This will aid anyone who wishes to proceed further in the study of the subject, and most of the papers referred to can be found in the scientific libraries scattered about the country.

I owe my thanks to Miss K. E. Burnand, who has assisted me all through with the manuscript, references and index, has also helped me in reading the proofs, and has saved me much labour and time.

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INSECTS

CHAPTER I

INSECT STRUCTURE AND CLASSIFICATION

If the average man be asked if he knows an insect when he sees it, he is scornful, but if he is cross-examined on the subject, his knowledge is usually found to be limited to recognising certain creatures as insects because they have been definitely pointed out to him, or because they look like something which has been brought to his notice. Hence the majority of people regard centipedes and spiders as insects, and some, like the notorious railway porter, perhaps include tortoises.

It is said that one man, on being asked the breed of a particular dog, regretted that he was not good at entomology, but perhaps the dog reminded him of something.

Insects form part of a very large group in the Animal Kingdom, known as the Arthropoda, which possess legs composed of several pieces or segments. They also have their bodies composed of a series of segments arranged one behind the other, but this is not peculiar to them, since other groups —the worms, for instance—are similarly "segmented animals."

Whereas the worms are soft without any hard supporting structures, the Arthropods have a hard outer layer which not only acts as an armour plating to protect them from attack, but also forms a suitable attachment for muscles on its inner face. This was an essential factor in the production of an animal capable of considerable muscular effort for propulsion in water or on the land.

The body segments of the Arthropods are grouped together to form recognisable parts, a number together forming a head, others together forming a mid-body or thorax, and the remainder forming the abdomen. The segments may be fused up so that they can

no longer be recognised as separate segments, as in the head or, in crabs, lobsters, and others, in the head and thorax together, or they may remain recognisable, as they mostly do in the thorax and abdomen. One of the characters of the Arthropod is, however, that in the primitive forms, each segment possessed a pair of appendages. Those on the head assisted in bringing the food to the mouth and in grinding it up ready for swallowing; those behind the head were walking and swimming appendages, some of the abdominal ones being specialised in connection with reproduction.

Thus, since the head of the insect bears four pairs of appendages—antennæ or feelers, jaws or mandibles, accessory jaws or maxillæ, and lower lip or labium—it is composed of at least four segments, although there is evidence that either two or three more segments are concerned in its composition.

The insect thorax is the centre of locomotion, and consists of three segments, each bearing one pair of legs; and two pairs of wings,

when they exist, are borne by the second and third segments. The structure of the thorax is strengthened, especially in the second and third segments of the winged insects, because of the large muscles which it contains. These two segments are usually fused firmly together, whereas the first segment, which only bears a pair of legs, is usually not closely fused to the others, in some cases its lower and lateral parts, to which the legs are attached, being only joined to the rest of the segment by membrane.

The legs are adapted for running, jumping, slow walking, climbing, and for swimming, according to the habits of the insect, running legs usually being long and thin, jumping legs usually possessing very large thighs or femora, slow, walking legs being usually short and thick, climbing legs longer and armed with strong claws, while swimming legs are usually flattened and feathered with long hairs. The specialisations usually affect the hind-legs more than the others.

The wings originate as bags filled with

blood, which become flattened, and the membrane thus formed is strengthened by a number of " veins " which run out from the base.

The primitive insects did not possess these, and there still exists a group of these wingless insects, descended from wingless ancestors.

The abdomen is the centre of digestion and of reproduction, and it is therefore constructed on different lines from the head and the thorax. During a meal the insect requires some capacity for expansion, in order to store and digest the food, and the expansible region is the abdomen. Expansion is also necessary for the female developing her eggs, and, as some insects lay about ten thousand eggs, while others, which continue developing and laying eggs for a long period, swell up to many times their original bulk, the abdomen requires to be extensible. This is achieved by these segments possessing armour plating above and below, which does not meet at the sides, and by each segment being separated from the next by intersegmental membrane,

and it is these membranous regions which are elastic.

The insect has lost almost all the appendages from the abdominal segments, only one pair of feelers, the cerci, being commonly found at or near the posterior end of the body, and two pairs near the posterior end being modified to form the sexual armatures of the male and female.

Internally the insect possesses an alimentary canal which consists of three parts, the anterior and posterior parts being formed by the inpushings of the outer skin; in consequence of which they are lined with the same horny material, known as chitin, which forms the hard shell of the body. The mid-gut arises within the body, and joins the fore- and hind-guts, so as to form a complete canal from mouth to anus.

The fore-gut usually possesses a pair of salivary glands, although these are not present in all insects, and in some insects additional glands open into it. This region of the gut is often enlarged posteriorly into a sac-like

æsophagus, in which some digestion is carried on, partly by the salivary fluid and partly by digestive fluids which pass forward into it from the mid-gut, through a filtering apparatus, the proventriculus or so-called "gizzard."

The mid-gut is the chief centre of digestion and of absorption. The hind-gut, at its anterior end where it joins the mid-gut, has one or more pairs of thin tubes connected with it. These wind about in the body of the insect, are bathed in blood, and absorb waste products, passing them on to the gut. They function somewhat like the kidneys in higher animals, and are known as "Malpighian tubules."

The circulatory system is the result of the breaking down of an ancestral system which probably consisted of arteries and veins. The insect possesses a segmented heart, which lies in the median dorsal line of the abdomen, and, from the front of this, there runs forward a vessel, the aorta, which in the head divides into two branches. These are all the recog-

nisable vessels, the rest of the system having become varicose and bulged out, like an over-blown inner tube of a bicycle, until all the internal space in the body of the insect not occupied by the organs has become a blood cavity or "hæmocœl." Thus all the organs are bathed in blood. The circulation is set up by the heart, which pumps the blood forward into the aorta and so through the head into the hæmocœl, and is assisted by accessory pumps, situated in different positions—for instance, at the base of the antennæ in some insects, and in the legs of others. As the bodies of many insects, especially in the young stages, are transparent, and as the blood contains spindle-shaped corpuscles, the circulation can be watched under the microscope.

The respiratory system of the insect is almost unique in the Animal Kingdom, only occurring elsewhere in the Centipedes and Millipedes, which may have received it from a common ancestor with the insects, and in the Arachnida, a group of Arthropods including the King-crabs, Scorpions, Spiders, Ticks and

Mites. Among the Crustacea the so-called Slaters or Woodlice seem to have started the same idea, but have not yet got very far with it.

In all other animals there is a definite respiratory centre, the lungs in mammals and the gills in fishes, where the blood is brought into close contact with the surrounding medium, being only separated from it by a thin membrane. Here the red colouring matter of the blood, the hæmoglobin, picks up the oxygen from the air or water and carries it to all parts of the body.

In the insects the blood has little or nothing to do with respiration, and there is a system of tubes, or " tracheæ," branching and re-branching throughout the body, which carries the air to wherever it is required. The main tubes originate by inpushings of the outer surface (in the same way as the fore- and hind-guts), and inside the body these unite to form the large tracheal trunks. Some or all of these inpushings or " spiracles " remain open, in order to keep communication between the tubes and the outside air.

Although the three thoracic and the first nine of the abdominal segments may each bear a pair of spiracles, yet no insect has more than eleven pairs, and most insects have ten pairs or less. No insect has spiracles on the head.

The larger tracheal tubes are strengthened by being lined with spirally wound thickenings, which, like the spiral wire in the hose-pipe, prevent them from kinking.

We have shortly discussed these internal systems of the insect because they are specially characteristic, and we shall have to refer to them again, but with regard to other parts of the internal structure, and for further details of those mentioned, we would refer the reader to G. H. Carpenter (2) or to Imms (12).

We have already referred to the fact that the primitive insects were wingless, and that they gave rise to the winged ones. As to the origin of these structures there are various views, but the most favoured one seems to be that the projecting flaps first arose as gills, which were thin-walled respiratory structures

in which tracheal tubes ran from the body, and which were possessed by primitive insects which lived in the water; that the ancestors came out of the water, and that these flaps enlarged and their muscles increased until they were capable of supporting the insect in the air. Another view is that the wings were new structures which began to develop, and which apparently were useless until they had become wings.

It is a little difficult to imagine structures developing through useless stages, and that is why the gill theory is more probable, because we can imagine the origin of the gills being associated with the thickening of the armour plating for protective purposes. While the skin remained thin, respiration took place through it, but as it thickened, certain areas remained thin for respiratory purposes, and bulged as the general body surface became less porous.

Should it be asked why the wings developed on the thorax and not on the head or abdomen, the answer is that the lifting power must be

situated over the centre of gravity, and that an insect flying vertically head up or down would be less capable of avoiding attack from an enemy, and would therefore be more likely to be eliminated in the struggle for existence—that is, by natural selection.

Thus the wings developed on the body, and in many of the winged insects we can see them appearing as small pads, soon after the young hatches from the egg, and gradually attaining their full size. In other insects, however, no wings are visible for a long time after the insect hatches from the egg, and when they suddenly appear they are quite large structures, about half their full size. In the caterpillar, for instance, which may live many months or even several years, there are no visible wings, and these do not appear until the caterpillar changes into a pupa, when the wings, about half the length of the pupa, are to be seen glued down upon the body. A dissection of a well-grown caterpillar, however, reveals the fact that the wings are there, but are developing in pockets in the sides of

the segments, and that their sudden appearance in the pupa is due to the pockets being turned inside out at the change.

It was not until 1898 that the significance of this, from the point of view of classification, was recognised, and it was at the Fourth International Congress of Zoology in that year that Dr. Sharp founded upon it a new system of classification. He showed that it was an advance in evolution upon the external development of wings as seen in such insects as Cockroaches, Grasshoppers, Dragon-flies, and Bugs, and he therefore divided all the winged insects into two groups—the *Exopterygota*, those in which the wings are visible as pads soon after hatching, and in which the pads increase in size until they become full-sized, and the *Endopterygota*, those in which the wings develop in pockets and do not become visible until the pockets turn inside out, far on in the life of the insect.

We therefore divide all insects primarily into two groups—the *Apterygota*, those which are wingless and which have descended direct

from wingless ancestors, and the *Pterygota*, the latter being divided into *Exo-* and *Endo-pterygota*.

Although in the process of evolution insects have developed in many directions, certain lines along which evolution has taken place stand out clearly in a study of entomology. First, there is a tendency to a fusion of segments, so that whereas, in primitive insects, the three thoracic and the eleven abdominal segments are easily recognisable, in the higher insects, because of the strains caused by the action of the wings, the thoracic segments have thickened and the second and third have fused together, and further, it is rare to be able to recognise all the abdominal segments. Secondly, although the primitive winged insects possessed two pairs of wings of similar size and consistency, the tendency has been to stiffen the anterior wings, making them of less use as organs of flight, but more useful as a protection to the back when they are at rest. This has put more upon the hind-wings, which have consequently become

larger. This tendency has not been universal, but is recognisable in many insects. The small dragon-flies, for instance, have two pairs of similar wings, so have termites (the so-called "white ants"), and many others of the simpler-winged insects. The larger, thick-bodied dragon-flies have the two pairs of wings of the same consistency, but the hind-wings are broader. The cockroaches, grass-hoppers, and their relatives have the front wing narrower and stiffened, while the hind-wing is broader and altogether more useful as an organ of flight, and this process has reached a climax in the beetles, where the front wings are no longer of any use for flight, having become thick "cases" which are a very efficient protection to the hind body and the hind pair of wings. The latter have now all the carrying work to do, and to this end they have become much longer than the fore-wings or "elytra," and, in order to get beneath these when at rest, they have developed a special hinge, which enables the apex to fold over the base, a characteristic found in no

other insects. The tendency has not been general throughout the insects, since we find butterflies and moths, bees and a large part of the bugs using all four wings for flight and showing no thickening of the front ones.

Another line of evolution in insects has been towards taking liquid rather than solid food, and this has been associated with changes in the form of the mouth-parts. These parts consist of a pair of mandibles or jaws, which, in the more primitive insects, are adapted for biting and chewing solid materials, and are outside the mouth. Beneath these mandibles is a pair of accessory jaws or maxillæ, whose function is to sweep up the bits chewed by the mandibles and direct them into the mouth, and beneath these again is a lower lip, or labium, consisting of two appendages fused together, and this forms a kind of table upon which the maxillæ do their sweeping. Such mouth-parts, adapted for biting and chewing, are described as "mandibulate," and in many insects of different Orders these mouth-parts have been modified, sometimes very little and

sometimes so greatly that other evidence is necessary to determine that the new type has really evolved from the other.

Among the Exopterygote insects we find that the bugs have developed such elaborate mouth-parts that the labium has become a long trough in which lie the mandibles and maxillæ, now converted into long stylets and, as all the bugs have these mouth-parts, embryology alone assures us that they are identical in origin with the mandibulate type.

Among the Endopterygotes we find the beetles with the typical mandibulate type, but a few groups have experimented with the object of taking liquid food. For instance, the larvæ of the carnivorous water-beetles of the Family Dytiscidæ have a fine tube running through each mandible, which is a sharply pointed, thinly built structure eminently suitable for piercing soft objects. The mouth is so constructed that it opens when the mandibles are spread apart and closes when they meet in the food. The latter consists of living insects, worms, tadpoles, and

so on, and these are captured by the mandibles, which close upon them and pierce into them. The Dytiscus larva then pumps out, through the fine tubes, a digestive fluid which dissolves the prey, and the solution is then sucked up through the tubes, although small solid particles may be taken in at the open mouth when the mandibles are spread open to change the hold.

In the same way the larvæ of the Glow-worm (*Lampyris*) and the larvæ of the Whirligig Beetles (*Gyrinidæ*) have perforated mandibles which probably function as in the Dytiscus larva.

A few beetles have their maxillæ lengthened out and grooved along the inner face, and so constituted that the two can be brought to-together to form a tube, which sucks the nectar from flowers. The best developed of this type is to be found in a form Nemognatha, of the Family Melöidæ, which is a perpetual frequenter of flowers, and this type is particularly interesting because the long proboscis of the butterfly and moth is formed in exactly the

same way, by the lengthening out of the maxillæ, almost all the members of this Order having this type; but they have improved upon the beetle, since their proboscis will curl up under the head when not in use, whereas that of the beetle will not.

In the bees we see all stages in the evolution of elaborate and lengthened mouth-parts, such as are found in the humble- and the honey-bee, from mouth-parts almost of the typical mandibulate type, although these simpler mouth-parts are not for the purpose of biting and chewing food. The lower lip is broadened out, and is used as a paint brush, partly for licking up the nectar from shallow flowers, but also for lining the walls of the galleries, dug out in the soil or in rotten wood by the mandibles, with a fine layer of saliva which sets as a kind of varnish.

One further line of evolution must be mentioned, and that is the gradual complication of the life-history, a subject which will be fully dealt with in the next chapter. It is associated with the change from Exopterygote

to Endopterygote, and has to be mentioned here because we are now going to discuss the basis of classification of the insects.

We have already seen that Dr. Sharp's recognition of the importance of the difference between external and internal development of wings gave us a basis for dividing up all insects into the primitively wingless Apterygota and the Exopterygota and Endopterygota, but insects are further divided into Orders, and these are largely based upon the characters we have been discussing—namely, the nature of the mouth-parts, the nature of the wings, and the complications of the life history.

We now have about twenty Orders of insects, and the following is a short classification. Some authorities make a few more Orders by breaking up some of those mentioned here.

Group I. Apterygota. Primitively wingless insects.

Order I. Thysanura. Longish insects, very simple in structure, with

long antennæ on the head and a long pair of cerci or feelers at the tail. Mostly live under stones and in earth in damp conditions.

Order 2. Collembola. Short insects, which have developed certain special structures, *e.g.* a "tail" bent under the body and held by a hook. The "tail" can be released suddenly, whereby the insect leaps into the air. Mostly live under damp conditions and many on the surface of stagnant water. Known as "spring-tails."

Group 2. Pterygota. Winged insects.

Sub-group I. Exopterygota. Wings developed outside body. Three stages in the life history: egg, nymph, and imago or adult.

Order 3. Orthoptera. Earwigs, Cockroaches, Grasshoppers, Crickets, Praying Mantids, Leaf and Stick Insects, etc. Young and adults

mostly live under the same conditions.

Order 4. Plecoptera or Perlaria. Stoneflies. Nymphs aquatic.

Order 5. Isoptera. Termites, so-called "White Ants." Social Insects; *see* Chapters VII and VIII.

Orders 6 and 7. Embioptera and Pscoptera (or Copeognatha). Two smaller Orders at one time placed with the Isoptera in one Order, Corrodentia. The Psocids are "Book Lice," but are by no means confined to houses. The Embiids show the elements of social life.

Order 8. Ephemeroptera. The Mayflies. Nymphs aquatic. The Mayflies are remarkable because the nymphs hatch out into a winged stage, the sub-imago, which moults and becomes the real imago.

Order 9. Odonata. The Dragonflies. Nymphs aquatic.

Order 10. Anoplura, including the sub-order Mallophaga, the biting lice, many of which are found on birds, and the sub-order Siphunculata, the sucking lice, which have developed a special type of sucking mouth and which feed upon the blood of animals. Almost certainly derived from the Psocoptera.

Order 11. Thysanoptera. The Fringe wings. Minute insects with peculiar sucking mouth-parts and which do considerable damage to crops. They are related to the Bugs.

Order 12. Rhynchota or Hemiptera. The Bugs. The name Hemiptera is unfortunate. It means half-winged, and refers to the fact that one group of the Bugs has the basal part of the upper wing stiffened and the apical part membranous. It only applies to one of the sub-groups, whereas Rhynchota, which means "snouted insects,"

applies to both. Bugs are mostly sap-feeders, but some are blood-suckers. All with highly specialised suctorial or "haustellate" mouth-parts.

Sub-group 2. Endopterygota. Wings developed in pockets, and not becoming visible until the pockets turn inside out when the wings are well grown. Four stages in the life history: egg, larva, nymph or pupa, imago.

Order 13. Neuroptera. Ant-lions, Lacewings, Alder-flies, etc., the last-mentioned Family having aquatic larvæ. Mandibulate mouth-parts, but adapted for sucking in the Ant-lions, Lacewings and their relations.

Order 14. Mecoptera. The Scorpion-flies. With one possible exception, the larvæ live in the soil. They are carnivorous, with mandibulate mouth-parts.

Order 15. Trichoptera. Caddis-flies. An aquatic Order, the eggs, larvæ, and pupæ being in the water. Many of the larvæ make cases of bits of vegetation, shells, or grains of sand, which they carry about with them, while others make cases fixed to stones, etc.

Order 16. Lepidoptera. Butterflies and Moths with sucking mouth-parts and scale-covered wings.

Order 17. Coleoptera. Beetles. With biting mouth-parts and fore-wings (elytra) stiffened, and forming a protection to the hind-wings and body.

Order 18. Strepsiptera. The extraordinary parasites such as Stylops, whose life-history is given in Chapter IV. Derived from the Coleoptera, and probably better included in that Order.

Order 19. Hymenoptera. Ants, Bees, Wasps, Sawflies, and Wood-Wasps,

Gall-flies, Ichneumons, Chalcids, etc.

Order 20. Diptera. Flies. Mouth-parts suctorial. Only two wings, and these the front pair, the hind ones being reduced to small drum-stick-like structures bearing sensory organs.

Order 21. Aphaniptera. Fleas. Wingless insects related to the Flies. Blood-sucking parasites with suctorial mouth-parts.

CHAPTER II

LIFE-HISTORY

WE have seen in the previous chapter that the insect is encased in a horny material known as chitin, and that the fore- and hind-guts and the main tracheal tubes are formed by inpushings of the outside. Therefore these parts are lined with chitin. Now chitin is a peculiar material; it is secreted by the cells which cover the body of the insect, and while it is fresh and new, it is elastic and capable of considerable expansion, but it gradually oxidises in the air and loses its capacity for stretching.

Thus the insect, when it hatches, can expand for some time, but after it may be a few days, or it may be much longer, the chitin has stretched all it can, so that further increase in size is impossible, and, under these circum-

stances, the insect does a strange thing: it begins to form a new layer of chitin inside the first. When this has taken place, the outer layer is completely separated from the living cells, and possibly irritates the owner in some way.

At any rate, the insect ceases to feed, and begins to hump itself up inside the old skin by trying to push forward with its tail. This puts a strain upon the old skin, which splits on the head and down the middle of the back as far as the front part of the abdomen, and the back of the insect, very pale in colour, begins to bulge through the slit. Great efforts are now made, and the head is slowly withdrawn from the old skin, the delicate antennæ or feelers and the mouth-parts all being pulled out, and, in addition, the lining of the fore-gut being left behind as the head is drawn clear. The legs are now withdrawn, and as these lift the body out of the shell, the linings of the main tracheal trunks can be seen pulling out of the large spiracles along the sides. The insect then walks out of its

old skin, the lining of the hind-gut being left behind, as was that of the fore-gut.

Thus is the moult completed in the vast majority of insects, and it is a very delicate period in the life-history. The pale body which emerges quickly expands, so that, immediately after emerging, the insect is much larger than the skin. The colours quickly appear, the new chitin hardens off in the course of an hour or two, and the insect then commences another feeding period. The process is repeated after a longer or shorter interval. The number of moults which takes place during life differs in different groups, in different species, and even within the same species. The dragon-fly, for instance, may become adult after ten moults, or as many as fifteen may be passed through, the number depending, among other things, upon the rate of growth of the individual, which, under cold conditions and with less food, takes longer to grow up and passes through more stages, marked off by moults.

The adult always emerges by a moult, and

where there is a larval stage, it passes into the pupal by a moult, all other moults taking place during the life of the larva or the nymph, as the case may be, with the single exception of the mayflies, where there are two winged stages, a sub-imaginal and an imaginal.

The moult is useful to the insect in another way, as it is an act of excretion, various waste products being passed into the chitin during each stage, and these are, of course, got rid of with the skin. In discussing the classification of insects it was mentioned that the Exopterygote passes through three stages—the egg, nymph, and adult or imago—whereas the Endopterygote passes through four stages—egg, larva, nymph or pupa, and imago. Although most entomologists now regard the larva as the new stage which has appeared in the life-history of the higher insects, the pupa thus being regarded as the homologue of the nymph, there are those who regard the pupa as the special peculiarity of the higher insects. They point out that in its most complete state it is a period of rest

between the feeding and growing larval stage and the adult condition; that more or less active pupæ occur in the less complex of the Endopterygotes, and that, in the Exopterygotes, the last stage of the nymph is often quiescent : in fact the pupal stage is the conversion of the last nymphal stage.

If this view is correct, then what we have called the larva is the homologue of the nymph of the Exopterygote, and yet there are remarkable differences between the two. In the first place, the nymph has compound eyes similar to those of the adult—that is, eyes composed of many units packed together. On the other hand, the larva, with one or two exceptions which are of no significance for this point of view, has simple eyes, separate units. The nymph has the same type of mouth-parts as the adult, whereas the larva always has a simple type, irrespective of its adult. The nymph develops its wings externally, whereas the larva develops them in pockets. The nymph tissue grows and increases by cell division until the creature becomes an adult,

while the larval tissue in simpler types increases to some extent by cell division, but undergoes a process of " rejuvenation " in order to become adult tissue. In the highest types, however, the larval tissue increases the size of its cells, but undergoes no cell division, and dies at the change from larva to pupa, the adult tissue all being developed from a number of groups of cells known as " imaginal buds," scattered about in the body, which begin to proliferate rapidly as the larval tissue dies. These imaginal buds are found in all larvæ, although they contribute less to the development of the adult in those forms where rejuvenation takes place, the rejuvenation consisting in the throwing out by the cells of some of their contents.

We see therefore that there are good grounds for regarding the nymph and larva as being very distinct from one another, and, on the other hand, there are good grounds for regarding the pupa of the Endopterygote as identical with the nymph of the Exopterygote. Both consist of tissue which is identical with adult

tissue; both have external wings; both have compound eyes, and both have the same type of mouth-parts as the adult into which they will develop. If then we adopt this view, we have to explain where the larval stage has come from, as it appears to be something quite new, suddenly thrust into the life-history; and yet the explanation seems to be simple. The Exopterygote eggs have a plentiful supply of yolk, so that the embryo gets good nourishment, and its tissues reach the end of the embryonic existence by the time that it is ready to hatch; the nymph therefore emerges in an advanced stage of development. The eggs of the Endopterygota, on the other hand, have less yolk, the quantity being very much less in some, such as the "parasitic wasps" (*see* Chapter IV) and flies than in others. The embryo therefore is badly nourished, and emerges from the egg in a much less developed state than in the Exopterygote, and this precocious embryo has had to adapt itself to its environment, and has become the larva.

The simpler larvæ which emerge from eggs with more yolk are elongate, active, thick-skinned creatures more like nymphs, and, like them, resemble in shape the primitive insects of the Thysanura. This type of larva has therefore been named after one of these insects "campodeiform."

The less simple larvæ are thin-skinned with head and mouth-parts less developed and the legs short or absent. This type has been named "eruciform," which literally means "caterpillar-like"; and the caterpillar, bee, grub, and fly maggot are examples. The adaptations to different environments have led to modifications in form, and the same larva may change its form during its life, a phenomenon known as "hypermetamorphosis," and referred to in detail in Chapter VI.

We have now outlined the life-history of the insect so far as to show that there are three fundamental types: one in which the insect merely grows up without metamorphosis, the most primitive, and still to be seen in the

simplest insects of to-day; a second in which the young differs somewhat from the adult and undergoes partial or incomplete metamorphosis, and a third in which the young is very different from the adult, lives under quite different conditions, and undergoes complete metamorphosis to reach the adult condition.

The difference between these three types is due to the process of evolution by which more complex forms have arisen from more simple, but just how this has come about is still in dispute. There are those who regard it as the result of an internal "urge" which has existed ever since life appeared, results of which are only controlled by the environmental conditions.

If the internal "urge" produces a variation favourable to the organism in its struggle to survive, the variation endures, but if the result is unfavourable, the organism is eliminated, this elimination being what Darwin called "natural selection."

On the other hand, there are those who regard the environmental conditions as the

only " urge," and look upon the vast variety of form and structure in living things as due to the plasticity of the organism in adapting itself to its surroundings and passing on these adaptations to its offspring, natural selection presumably trimming out the less well adapted. This question as to the inheritance of acquired characters has long been in dispute, and until recently no evidence has been forthcoming which was unassailable.

Recently, however, Dr. Heslop Harrison, working with moths, has obtained results which seem to justify the view that such characters may be passed on to the offspring after the cause which first produced them has ceased to exist (10).

But whatever may be the actual cause of variations in form and structure, there are what Wheeler calls " appetites," which the organism is perpetually striving to satisfy (27). There is hunger and there is reproduction, both of which lead to competition between individuals, and there is fear, which is excited by " harmful and disagreeable stimuli,

usually of external origin," which have led to reactions on the part of the organism, and these, through succeeding generations, have become instinctive.

This looks very much like accepting wholeheartedly the theory of the inheritance of acquired characters, but it is possible to escape this by saying that the power to react was inherent in the organism, and that those individuals which could not react, or failed to react in the right way, were eliminated by natural selection, and thus reaction became more and more perfect through succeeding generations by the perpetual elimination of the failures.

However, these appetites are factors which have led to the adaptation of the organism to its environment, and the life-history of a species is the story of its adaptation. We will therefore discuss the habits of insects as they have developed in relation to these appetites.

First, with regard to feeding, there is the most extraordinary diversity of habit amongst insects. Though a vast number of species

feed upon the leaves of plants, some chewing up the whole tissue and others mining within, others feed upon the roots, and others again on or in the stems. Many forms are parasitic upon animals, living amongst fur or feathers, or burrowing in the skin, or living in the gut. We are all familiar with the clothes moths, which thrive upon the very dry diet of fur, feathers, and wool, and we only regard as disgusting such forms as live in wet, putrefying organic material. Skins, leather, books, furniture, and all kinds of food material which we store up for our own use have their special insects. Plants which are poisonous to most forms of animal life form a suitable food for some insects. Cayenne pepper and even Pyrethrum Powder form a suitable pabulum for a few kinds. A few years ago a bottle containing argol, a deposit which separates out in barrels of wine, and which contains about 80 per cent. of potassium tartrate, was found, in the Chemical Laboratory at Cambridge, to be swarming with a small beetle. The dust on the floor of a dirty house provides

suitable food for the larvæ of fleas, and there is almost no end to the list of materials which provide nourishment for insects.

But although the more primitive insects lived upon food material which they chewed up, there has been a tendency amongst insects, as we have already seen in the previous chapter, to change over to liquid food, and the mouth-parts in different forms have become elaborated for this purpose.

Now liquid food may either be obtained superficially—as, for instance, the nectar oozing from the nectaries in flowers—or it may be obtained by piercing the tissues, and different methods have been employed for doing this. In the first place, a lengthening out of the mouth-parts has in most cases taken place, but there are some forms in which this has not occurred.

In a few cases the mandibles or jaws have become sharply pointed, and a tube has developed in them, opening on the inner curved edge just below the piercing point. Now the jaws are, of course, movable structures, which,

however, are not inside the mouth, as they are with us, but outside it. They also move out on either side, not up and down. It is obvious, therefore, that a tube running through them, and with an opening near the base, would be perpetually varying its position, and yet, if such a tube is to be of any use in connection with feeding, it must communicate with the mouth. It is therefore so placed that, when the jaws are brought together in the food material, the tubes communicate with the corners of the mouth, so that the insect, having seized its prey and closed its jaws upon it, can suck in the juices of the prey through them. This adaptation is very beautiful, since it is only when the prey has been captured that there is any necessity for the sucking apparatus to come into play.

But this apparatus is also adapted to another purpose. The process of digestion in any animal consists in applying to the food digestive fluids which act upon certain ingredients and dissolve them, and it is this solution which is ultimately absorbed by the walls of

the alimentary canal. The insoluble parts of the ingested food are ultimately voided. Most of the insects which take liquid food do a large part of their digestion outside the body, as they regurgitate a digestive fluid on to or into the food, and then suck down the dissolved material. And those insects with tubes through their jaws pour out a digestive fluid into the prey and suck down the products.

A good example of this process is to be seen in the larvæ of the great diving-beetle, Dytiscus, referred to in the previous chapter, which feeds upon worms, tadpoles, insect larvæ, etc.; and, as the head is transparent in most of these larvæ, it is possible to see the sucking pump at work, and every now and again reversing its action and driving out fluid through the tubular jaws.

The larvæ of the glow-worm beetle and of certain relations has, like that of the Dytiscus, tubes through its jaws and, although these tubes function in the same way as in the latter, they have here a very special purpose. The larva feeds upon snails, and these animals

readily retreat within their shells when disturbed, so that the chance of a beetle larva being able to pierce the snail's tissues except through the very tough " foot " would appear to be very small. But the beetle larva climbs upon the shell of a moving snail and suddenly drives its two jaws into the animal, and at once pumps out a digestive fluid into the snail. This fluid instantly paralyses the snail, which is unable to contract into its shell and so becomes an easy prey.

The larvæ of ant-lions, like those of the beetle just mentioned, have developed piercing and sucking tubes, but they have done so in another way. They live in dry, sandy areas, where they form little pits, at the bottom of which they lie in wait for any insect which may slip over the edge. Such an insect naturally struggles to climb out of the pit, and could easily do so if undisturbed, but, in making the attempt, loose grains of sand fall down the sides to the bottom, and indicate to the ant-lion the presence of a visitor. The larva at once becomes active, jerking up sand

by digging its flattened head into the side, and this sand, falling upon the struggling insect, confuses it and causes it to struggle wildly, so that, instead of escaping, it quickly slips down to the bottom. Here it is at once seized by the ant-lion larva, which proceeds to pierce it and suck its blood. Ants are the most usual prey of these insects: hence the name.

The piercing structures in this case are a curved and sharp-pointed mandible or jaw hollowed out beneath, and a similarly shaped maxilla or accessory jaw hollowed out above, so that, on either side of the mouth, a mandible and a maxilla together form a piercing structure and a sucking tube.

In these examples the sucking apparatus has been stiff and strong, eminently capable of puncturing the soft tissues of the prey, but there are insects, such as aphides or "green-fly," some of which live upon comparatively soft plant tissues, while others live upon the much tougher tissues of buds and branches of trees. Some of these have exceedingly long

and very fine mouth-parts, and an examination of them and of the tissues which they penetrate makes it impossible to believe that they are driven in by sheer force. The explanation appears to be that, although the insect may take advantage of natural pores and spaces in the plant, such as stomata, lenticals, and intercellular spaces, " external digestion," already referred to, plays some part in the penetration process. The insect pumps out a salivary fluid, which dissolves cell-walls, and thus opens up a way for the passage of the very fine sucking apparatus.

The increase of individuals seeking the same kind of food is perpetually inducing dispersal, and has probably been one of the chief causes of the existing distribution of animals. There has thus frequently arisen an adaptation in the organism to this end.

In the aphides already referred to, and also in scale insects, the mother in many species, having found a suitable feeding spot and buried her sucking apparatus, never moves from the spot, and lays her eggs where she is fixed.

The nymphs when they hatch are very active for a short time, and they in turn settle down, the females for life; and thus it is just those few hours during which the dispersal of such insects is possible.

Many of the aphides, however, are not so restricted, but produce, at certain periods, winged individuals, which fly to other plants, and the production of winged generations in the aphides has received a certain amount of attention. A typical life-history would be as follows. A single egg, laid by a female in the autumn, lies dormant through the winter, and produces a wingless female in the spring. She settles down to feed, and, within two or three days, produces a brood of about forty young ones like herself. These in turn do the same, and so these wingless, viviparous generations may continue throughout the summer, with an occasional appearance of either a winged generation or a proportion of winged individuals.

Towards the end of the season, when conditions are not so good, a generation of winged

individuals appears which contains males. These mate with the females, and these females lay each a single egg, which remains dormant through the winter.

It is not clear why the sexual generation occurs, although it is in some way connected with less suitable conditions, because, by keeping such a species in warm surroundings and with ample food, no sexual individuals are produced.

Various experiments have been made with the object of inducing a winged generation to occur, and a few years ago a worker in America stated that various substances introduced into the sap of plants, by watering the soil with a solution containing them, would lead to wing development. He found that he could produce nearly 100 per cent. winged individuals if he watered the food plant with, among other things, sugar, whereas in another experiment a weak solution of magnesium sulphate, applied for twelve to twenty-four hours, produced nearly 100 per cent. winged individuals of the rose aphis (28).

Since this work was carried out in 1918, several observers have failed to get these results, which suggests that some other factor which escaped notice was the real cause of the results obtained in America.

In connection with reproduction, it is only necessary to mention the attraction of the sexes for one another and usually the absence of attraction between males of one species and the females of another, and the special adaptations which enable the males of a species to find the females.

The assembling of males of the oakeggar and other moths was investigated by Fabre, who came to the conclusion that they possessed some sense unknown to us, and recently, suggestions, founded apparently upon very little evidence, have been made that insects possess some power of communication similar to wireless.

The habits of female insects in connection with oviposition have been the subject of various experiments. It has been found that smell plays a part, at least in certain insects,

and a little of the essential oil extracted from a cabbage leaf and smeared on paper will induce the cabbage butterfly to lay her eggs there. This might be suggested as merely a case of memory on the part of the butterfly of its own larval period, but experiments made upon the small garden white butterfly, in which, for several generations, the caterpillars were only fed upon one kind of food-plant, failed to produce a definite choice of that food-plant by the females. And this suggests that the female knows the food-plants suitable for her offspring by what is called "race memory," or the repetition through thousands of generations of an act which commenced as a response to some definite stimulus, and which has now become instinctive.

In connection with the choice of food material by the parent for the offspring, the habits of the solitary wasps are of interest. Each species stores up for its larvæ some special kind of food material; for instance, one will store caterpillars, another flies, another certain kinds of beetles, another

beetle larvæ, and so on, this material being first paralysed, and then packed into a cell where the wasp lays her egg, usually on the prey. This suggests that the larva, being strictly limited as to the food provided, would not thrive, and perhaps would not even eat any other kind; yet experiment has shown that a larva normally fed upon caterpillars will readily eat beetle larvæ; in fact, the larva is not particular as to the species of food provided for it. It is curious, therefore, that this state of things should exist, and again, it is probably to be ascribed to race memory rather than to that of the individual. Although in most cases the mother lays her eggs on, or in close proximity to, the food material, there are a number of exceptions where the larva has to find its food. The cases of many insects in which hypermetamorphosis occurs are examples of this, and a description of one such case will be found in Chapter VI, where the life history of the beetle *Melöe* is outlined.

The bot or warble-fly, whose larvæ cause

such damage to the skins of cattle that the annual loss on hides in Britain alone varies from two to seven million pounds, lays its eggs on the hairs of domestic cattle, the legs being the usual choice. The eggs hatch in a few days, and the larvæ crawl down the hair and bore into the skin, where they disappear. Two or three months later they are re-discovered in the walls of the æsophagus, presumably having got there by boring their way through the tissues, although this has not yet been observed. It has been suggested by one authority that they get into a small blood-vessel and are carried about by the blood, but the only basis for such a supposition is that the larvæ completely disappear from the spot where they penetrate the skin, and cannot be found anywhere until they reappear in the walls of the æsophagus. After, it may be, a few weeks in this position they work their way in the connective tissue, until they finally come to be beneath the skin on the back, where they give rise to a tumour, which causes a hole to appear in the skin (a "worm-

hole " which has become " warble "), through which they bring their one pair of spiracles into communication with the outside air.

Perhaps the most extraordinary adaptation in connection with life-history is that of a fly known as Dermatobia, a relative of the warble-flies, which occurs throughout the tropical parts of America, mostly in the wooded tracts of coastal lowlands and river valleys. It produces " warbles " on man and various domestic animals, such as oxen and dogs, although the horse is apparently immune. As this fly had never been seen laying its eggs, and as the eggs had never been found upon animals or on man, all sorts of theories were put forward. It was suggested that the eggs were laid on the ground, and that the larvæ crawled on to the animals and, in the case of man, that the fly laid the eggs on washing hung out to dry. In 1911, however, the eggs were discovered attached to the ventral side of the body of a mosquito, known as Janthinosoma, up to seventeen of them being neatly placed together. It was also

observed that they were only to be found on the female mosquito.

Now this mosquito is a blood-sucker, and the eggs of Dermatobia hatch while the mosquito is feeding, the young larvæ at once making for the wounded spot, where they enter the skin. How the eggs are placed upon the gnat is still a mystery, but it is reasonable to assume that the Dermatobia catches the gnat and deliberately lays her eggs upon it (22).

In connection with protective adaptations, the relationship between change of structure and change of habit stands out even more clearly than in the cases already cited. In the first place, many insects are so shaped and coloured that they closely resemble the surroundings in which they live. Thus many leaf-feeding caterpillars are green, while some are brown like twigs, and it is quite obvious that the success of their cryptic appearance depends upon their habits being suitably adapted. Thus a twig-like caterpillar which moves about all the time will readily attract the attention of a bird, and we therefore find

that cryptic colouring and form are associated with nocturnal activity.

But whereas we find many forms thus protected, we also find many with glaring displays of colour, in which yellow, red and black frequently predominate.

In most cases, however, such insects are more or less immune, since they possess some other quality which makes them either unpalatable or unpleasant in some other way to a would-be assailant. Moreover, these insects advertise themselves in every possible way. Whereas the cryptically coloured butterflies and moths fly with a rapid and zig-zagging flight, and become invisible on settling down, the bright-coloured ones have a lazy method of flight, and, when at rest, usually spread their wings so as to show their colouring to the fullest advantage.

In the same way the common wasp, with its sting as a protection, advertises itself by its black and yellow colouring, and all those insects and other animals which possess some means of defence and are brightly coloured

are described as exhibiting "warning coloration." Here we see something that is primarily for the benefit of the species, because insectivorous animals and birds learn by actual experience that these brightly coloured insects are not desirable as food. Therefore many individual insects are sacrificed so that the lesson may be learnt by the enemies of their race.

It is, however, to be noted that many different kinds of insects, even those belonging to different Orders, exhibit the same general warning coloration, so that, for instance, a black-and-yellow bug destroyed by an inexperienced bird helps to teach that bird that black-and-yellow-coloured insects are best left alone. Thus all those protected insects exhibiting the same general warning coloration form a kind of association of protected forms, and this was first pointed out by Fritz Müller, after whom it has been called "Müllerian mimicry."

There is, however, a very different kind of mimicry, known as "Batesian mimicry," in

which a form which is not unpalatable, and has not any defence apparatus such as a sting, closely resembles some other insect which exhibits the usual advertisements and possesses some means of defence. And here we see a peculiar adaptation in form and colour, because these mimetic forms no longer resemble their relations, but have completely gone over to a pattern exhibited by some other insect, it may be belonging to a different Order. And not only have these insects changed their colouring, but they have also diverged from the habits of their own relations. Thus while their sombre relations make themselves as invisible as possible, these others, flaunting bright colours, display them to the fullest advantage.

There is a further adaptation here which is of extreme importance to both parties involved, and that is the mimic, which having no protective qualities, must always be much rarer than the model. It is obvious that if an inexperienced bird found that two or three insects out of four or five of apparently one

kind were nice to eat, it would persevere in its investigation, and the mimic would gain nothing by its mimicry, while the elaborate adaptations of the model would also be of little avail.

In this chapter we have more or less confined ourselves to the considerations of adaptation in relation to life-history in general, but, as has been said, every life-history is a history of the adaptation of the species, so that the same theme is continued throughout the succeeding chapters wherever a life-history is portrayed.

CHAPTER III

ADAPTATIONS TO AQUATIC LIFE

As has been said in connection with the theory of the origin of wings from gills, the ancestors from which insects arose were aquatic, and the probability is that the first insects were terrestrial. At any rate, it is quite certain that the vast variety of aquatic forms which now exist are all descendants of terrestrial forms, and have become adapted to a life in the water. This accounts for the fact that, although representatives of thirteen of the Orders named in the first chapter have become aquatic, comparatively few are so well adapted that they can breathe the dissolved air, the majority having to return at intervals to the surface to renew their air supply.

Moreover, although we speak about aquatic insects, with one recently discovered exception, a fly which lives in the sea at Samoa, no

insect spends its whole life in the water, so that an aquatic insect must be defined as one which spends at least one stage of its life in the water. It is usually the nymphal or larval period, according as the insect is Exopterygote or Endopterygote, which is adapted to an aquatic life.

Eggs of aquatic insects may or may not be laid in the water; some are laid upon the vegetation on the verge, and the young have to make their way into the water when they hatch.

We shall see, in the chapter on Insect Parasitism, that it is not only among aquatic insects that the young has to do some work before it reaches its food.

When the eggs are laid in the water they may be dropped on the surface while the mother flies over it, and may then sink to the bottom. These eggs are usually sticky, so that the fine mud adheres to them and they become effectively concealed.

The mother may push her abdomen into the water while resting upon some projecting

plant, and lay her eggs upon the vegetation, or, provided with a piercing apparatus, she may insert her eggs in the tissues of the plant, or she may lay her eggs in a mass below the surface, in which case they are frequently bound together by a matrix which rapidly swells and becomes transparent and mucilaginous in the water, so that the eggs become separated from one another in the mucilage. Such egg masses may be globular or vermiform, and they may be sufficiently sticky to adhere to the vegetation, or they may be attached to it by a thin thread of mucilage which the mother deliberately fastens to the support.

Again, the eggs may be laid on the surface, either singly or in a mass, and in such a case they are usually unsinkable, unwettable, and self-righting. The importance of these qualities will be seen when we come to speak of the eggs of the gnat and mosquito.

Some insects ensure the floating of the eggs in a different way: they spin a silken cocoon for them, and this is attached either to

floating vegetation or to something which will keep it at the surface.

And this raises the question, Why should some eggs require to be at the surface, while others seem to get on quite well beneath it? All eggs of these aquatic insects require air for breathing purposes, and those at the surface get it easily, either exposed or in the silken cocoon. It is probable also that those buried in the tissues of plants get it, since all through many plants, and especially through submerged aquatics, there are intercellular air-spaces, upon which the eggs could draw for their supply. If such eggs are taken from the plants and allowed to sink, they do not develop, presumably because they are drowned. With regard to eggs embedded in mucilage and those which sink to the bottom, nothing seems to be known, but we must assume that they are perfectly adapted, and obtain their air from that dissolved in the water.

With regard to nymphs and larvæ, some are able, like submerged eggs, to obtain their air

from the water, like fish, and these are usually described as true aquatics. It is obvious that, to such an insect, spiracles for the intake of air would be useless, and consequently we find that, although they still exist, they are all closed, and the nymph or larva is "apneustic."

In some cases no special respiratory organs exist, the thin, transparent skin acting as the respiratory surface, but in other cases there are special respiratory organs in the form of gills. These may be single filaments or tufts of filaments, or they may be leaf-like structures, and such gills are found attached, sometimes to the sides of and beneath the thorax, and frequently along the sides of the abdomen. Into each gill there runs a tracheal tube, which usually branches, and the lamellate gills often resemble leaves, not only in shape, but also because the branching air tubes resemble the veins.

Although in the majority of such insects the gills project from the body, in the thick-bodied dragon-flies they are all enclosed inside

the rectum at the posterior end of the alimentary canal. It is essential for any insect with gills that the water round it should be frequently changed, because, once the gills have taken the oxygen out of the water bathing them, that layer of water is useless, and the insect is in danger of suffocation. Therefore gilled insects usually either live in running water or at any rate under conditions where the water is circulating, or they are capable of waving the gills so as to cause a circulation of the water around them. Thus in the case of these dragon-fly nymphs it is obvious that some system should exist by which they can change the water bathing the gills. This system is the circular muscle-layer round the rectum, which, by contraction drives the water out of the rectum, and by relaxing causes water to be sucked in again at the anus. Such a system seems liable to break down, because, if the water contains suspended particles of matter—as well it may—there is a possibility of one or more of these jamming in the entrance, and thus

causing the complete stoppage of respiration. This is provided against by a very simple filtering arrangement. Round the anus there project five pointed spines, which, when brought together, form a common point, but they can be spread out. Thus, by bringing the spines close together they act as a filter, and they can be separated to allow the fæcal matter to pass out and to allow the water inside to be driven out with some force.

The insect uses this respiratory apparatus for escaping from danger; it tucks in its legs to its sides and, by sucking in water and forcing it out rapidly, it shoots forward like a torpedo.

The thin-bodied dragon-flies have only a semblance of this respiratory apparatus, but they possess three large lamellæ at the posterior end of the body, which are gills. These gills, however, are not essential, as the insect breathes through the skin. It is to be noted, however, that if the lamellæ are cut off, the rectum can be seen through the transparent body, contracting and expanding more fre-

quently than if the lamellæ are present, suggesting that some slight respiratory function attaches to that part in these insects.

It is a curious fact that, in the last stage of the dragon-fly nymph, one pair of spiracles open, so that the insect is no longer a true aquatic or apneustic. If a younger nymph is placed in water which has been boiled so that all the dissolved air has been driven from it, the nymph is quickly in difficulties, and soon dies, but an older nymph in the last stage placed in the same water gets to the top and pushes part of its side out of the water, so as to bring the spiracle into communication with the air, and thus escapes suffocation. The so-called "caddis fly," which is more closely related to butterflies and moths than to flies, lays its eggs beneath the surface, and they are each embedded in a sphere of mucilage. The larvæ, when they hatch, are true aquatics possessing many filamentous gills, and not requiring to come to the surface for air. The majority make for themselves cases out of various materials, these being in the form of

tubes within which the larva lives, projecting its head and thorax out at the anterior end when it wants to feed or move. The larva has two methods of holding on inside its silk-lined case. On the first abdominal segment there are three projecting lobes, one on either side and one above. These can be bulged out so as to jam against the sides of the case. The posterior end of the body is armed with a pair of strong hooks, and these can be stuck into the walls of the case, so that it is very difficult to pull a caddis larva out. Under ordinary circumstances, the larva only holds on by the projecting lobes, and the body is constantly waving about inside the case. If a drop of coloured water is brought to the head of the insect without disturbing it, it will be seen that it is sucked into the case and shot out at the posterior end. The waving of the body is thus creating a current of water through the case which carries away the fæcal matter and constantly supplies the gills with fresh water.

When the caddis larva is full-grown it

anchors its case at the bottom and spins a silken net over the entrance, and, in the case, it changes into a pupa. Thus the pupa also is a true aquatic, and although this stage in insects is frequently spoken of as a resting stage, the pupa of the caddis never rests. It is perpetually waving itself about in order to ensure a circulation of water round it, and, shortly before the time arrives for the adult to emerge, it becomes specially active. By means of a large pair of mandibles it bites through the silken door and swims upwards, and with its long legs catches hold of the vegetation. It then deliberately climbs out of the water and, holding on to a stone or other support, the moult takes place and the caddis fly emerges.* The adult itself is well adapted to a life in the neighbourhood of the water, as it is unwettable and can flop about on the surface without fear of drowning, and can even climb down submerged vegetation. The adult insect apparently never feeds, and

* Some of the caddis flies emerge from the pupa as it floats at the surface of the water.

its mouth-parts are poorly developed, there being no mandibles. Thus the pupa possesses a pair for the sole purpose of opening the door of the case when it is ready to mount to the surface.

Those water insects which require atmospheric air are termed "false aquatics," and they are never apneustic; on the other hand, their adaptation to an aquatic life has frequently led to the closure of some of the spiracles, and often to the development of some kind of air reservoir in or on the body. The most usual arrangement is for all but the last pair of spiracles to be closed, this type being called "metapneustic."

In the carnivorous water-beetles, of which Dytiscus is a well-known example, the larva is metapneustic, and has no special reservoir. It comes to the surface at intervals, tail first, the eighth and last pair of abdominal spiracles being situated at the apex of the body. The full-grown larva crawls out of the water and buries itself in the earth, forming a cell in which it changes to a pupa, so that this stage

is terrestrial. The adult then appears, and returns to the water, but it can fly so that, although it only feeds and breeds in the water, it is not entirely aquatic. It has the full number of spiracles open, but the abdominal ones open into an air reservoir beneath the large wing cases, and the first and last pairs of these spiracles are much larger than the others. The beetle comes to the surface tail first to renew its air supply, when, apparently, not only is the air beneath the elytra changed, but also that in the large tracheal trunks.

The time during which the beetle can remain beneath the surface depends upon the temperature conditions and upon its own activity, as it gets "out of breath" if it swims very rapidly, and has to renew its supply more frequently. Half an hour beneath the surface is perhaps a normal submergence. In the autumn, however, some species bury themselves in the mud at the bottom, and remain there for four or five months, during which time respiration is practically suspended.

The so-called "silver beetles," which belong to a very different group from Dytiscus and have become adapted to an aquatic life quite independently of the latter, show some interesting differences in adaptation. Their life-history in general is similar—that is, the larva is aquatic and comes out of the water to pupate, the beetle returning to the water, but being capable of flight. The larva also is metapneustic, and it is in the adult that the main differences occur. Here there is not only a sub-elytral reservoir, as in Dytiscus, but the ventral side of the body is covered with a fine felting of hairs, and this is unwettable, and therefore holds a film of air. This gives the beetle a silvery underside, hence the name "silver beetle."

Whereas Dytiscus comes up tail first to renew its air supply, the silver beetle comes up horizontally, and breaks the surface film with its short, clubbed antenna on one or other side. This brings the ventral air reservoir into communication with the air, and this reservoir communicates with the sub-elytral one at the

sides of the thorax, so that both reservoirs renew their air by means of the antenna. Whereas the antennæ of Dytiscus are long and filamentous and are used solely as sensory organs, those of the silver beetles are apparently used only in connection with respiration when the insect is in the water, as they are tucked away under the sides of the head when not required for breaking the surface film. Their function as sensory organs is taken over by the palps attached to the maxillæ, which are longer than in most other beetles, in consequence of which the silver beetles and their relations have been grouped together as the "Palpicornia."

But these two groups of beetles are by no means the only ones which have become adapted to an aquatic life, each group having developed some special contrivance of its own; perhaps one other example will suffice.

There is a large Family Chrysomelidæ, or "golden beetles," so called because many of them possess a brilliant metallic colouring. One group of this family has become adapted

to an aquatic life, and the eggs, larval, and pupal stages are all passed beneath the surface. But the larvæ and pupæ are not true aquatics, and require atmospheric air, which most other false aquatics obtain by moving to the surface at intervals. These Donaciines, however, live in the mud below the water, and feed upon the roots of water-plants, and they obtain their air from the intercellular air-spaces in the roots. For this purpose the larva has, on the dorsal side of its eighth abdominal segment, a pair of sharp spines, which it drives into the plant tissue. Inside the base of each spine is a large vestibule into which opens the main lateral tracheal trunk. It is not clear how this vestibule communicates with the intercellular air, but there are fine grooves running along the dorsal margin of the spines, and these possibly communicate with the vestibules.

The larva pupates on the roots, and exudes round itself a secretion which forms an oval cocoon, at first transparent yellow, but later becoming dark brown. Apparently, before

changing to a pupa in this cocoon, the larva bites one or two holes in the plant tissue, and the air in the cocoon is kept fresh through these communications with the internal air in the plant.

The adult bites its way out of the cocoon and crawls up the plant stems out of the water, and spends its life on the herbage just above the surface.

One other insect has adopted this habit of utilising the air in plant tissues beneath the water, and that is the larva of a Gnat (*Tæniorhynchus*), and it does it in the same way—that is, by piercing the tissues and bringing the tracheæ into communication with the intercellular spaces.

The gnat and mosquito belong to an aquatic family in which only the adult does not live in the water. This is not strictly accurate, since in many species the eggs float on the surface, as, for instance, in the Gnats (*Culex*) and Mosquitoes (*Anopheles*).

We will outline the life-history of the Common Gnat (*Culex pipiens*).

The gnat lays its eggs on the surface of the water, to the number of perhaps three hundred, and these are elongate bodies pointed at one end. The female fastens these eggs together side by side, the pointed end uppermost, and the whole mass of eggs forms a raft which is slightly concave above. This raft is unwettable, unsinkable, and self-righting—that is, if it happens to be turned upside down it at once comes right way up again. The peculiarities of the raft are easily accounted for. The developing embryos require atmospheric air, and therefore the raft floats and remains dry, and when the time comes for the larvæ to hatch, it is essential that they should escape beneath the surface film; otherwise they would be caught in this, and would perish. They escape from the broad end of the egg, which is beneath the surface film.

The larva is a false aquatic—that is, it requires atmospheric air—and it is metapneustic—that is, only the last pair of abdominal spiracles are open, and they are carried up on the end of a long tube, the

" siphon," at the apex of which are some small flaps capable of being spread out or drawn together.

The larva is heavier than water, so that it normally sinks to the bottom, but, by a writhing movement, it can swim up and bring the apex of the siphon to the surface film. The spreading of the small flaps on the surface film is sufficient to hold the larva at the surface, and it can thus renew the air in the main tracheæ. When it wishes to sink, it merely closes the flaps and loses its grip on the film.

The antennæ bear tufts of hair towards the apex, and the mouth-parts are armed with stiff hairs. The larva feeds upon minute organisms, and the antennæ, by waving about, cause a current of water to circulate past the mouth. The small organisms catch in the hairs round the mouth and are swallowed.

Thus the larva can feed resting at the bottom or hanging suspended by its siphon from the surface film.

When the change to pupa takes place, certain other remarkable changes occur. For

instance, the pupa is lighter than water, and has to struggle to get away from the surface, and every time it ceases to struggle it floats up again. Further, the pair of spiracles which were open in the larva are now closed, and a pair has opened on the front part of the thorax, each spiracle being surrounded by a small trumpet. The pupal head is not heavier than the pupal tail, so that, when the pupa rises to the surface, the head and thorax are uppermost and the tail is downwards. Thus the spiracular trumpets break through the surface film.

Here again the reason for this change is easily explained. The Gnat has to escape from the pupal skin into the air, and, as the normal insect moult takes place by the splitting of the skin on the head and thorax (*see* Chapter II), that region must be at the surface for the escape of the fly. Secondly, it is essential that the pupa should lie dormant at the time of the escape of the gnat, and therefore the pupa is buoyant and remains at the surface without any swimming action.

Water insects are always found in comparatively shallow water, and it is easy to see why. The false aquatics would have to go far to travel up and down for renewal of their air supply if the water was deep, and the true aquatics would suffer, because there is less oxygen in the lower layers of deep water.

One insect, however, has become adapted to such conditions, and it was the only insect dredged up from the depths of Loch Ness; it has also been obtained from the bottom of the Lake of Geneva. This is the larva of a species of Harlequin Fly (*Chironomus*), which is also found in shallow water. It is peculiar in being one of the two or three known insects which contain hæmoglobin, the red colouring matter of mammalian blood. Now hæmoglobin is a respiratory pigment—that is, it can take up oxygen and can equally readily part with it—so that there is little doubt that under conditions where oxygen is scarce, as in the mud beneath the water, the pigment is of great use to the Chironomus larva.

One other insect which possesses hæmo-

globin does not live in the water, but in the gut of the horse. It is the larva of the Horse-bot-fly (*Gastrophilus equi*), and its life-history, like that of the warble-fly mentioned in Chapter II, commences by the eggs being laid on the hairs, usually on the fore-legs. Here, however, the hatching is induced by the horse licking itself; thereby the larvæ get on the tongue and so pass into the stomach, where they attach themselves to the walls by their mouth-parts. Under these conditions they are almost aquatic insects, as they are bathed in the fluids of the stomach, and are under great difficulties for their supply of oxygen. Like aquatic larvæ, they are metapneustic, and the spiracles open into large vestibules from which the main lateral tracheæ branch off. There are, however, branches of tracheæ which pass into groups of cells containing hæmoglobin, and, apparently, these cells are able to extract every particle of oxygen from the bubbles mixed with the food in the horse's stomach, which are seized by the larvæ.

As has already been said, every life-history is a story of the adaptation of the species to its environment, so that, although this chapter must now come to an end, the subject continues throughout the book wherever a life-history is outlined.

CHAPTER IV

REPRODUCTION

INSECTS are normally bisexual, like the vast majority of animals, and the two sexes are in separate individuals. "Hermaphrodites," or individuals possessing characters of both sexes, have been recorded, and occasionally such individuals possess both testis and ovary. More usually the gonads, or reproductive organs, are of one sex, but certain other structures, either internal or external, are characteristic of the other sex, such individuals being described as "gynandromorphs." The phenomenon has been recognised in many groups of the Animal Kingdom, and has been carefully studied, and the reader who is interested is advised to refer to Goldschmidt's book, of which an English translation by Professor Dakin was published in 1923 (9).

In normal reproduction the two elements concerned are eggs, which develop in the

ovaries of the female, and spermatozoa, which develop in the testes of the male. The egg as laid is enclosed in a "shell," which may be smooth or highly sculptured, opaque or transparent, and it may be spherical or elongate. One end of an elongate egg or one point on a spherical one is the anterior pole, and this end or point may be decorated with a small stalk-like structure, sometimes called the "pedicel," which surrounds a minute pore, the "micropyle," through which the spermatozoon finds its way to the interior. The anterior pole of the egg is always towards the inner end of the ovary in the body of the female, and is therefore the last to pass from the oviduct when the egg is laid, and, as the head of the embryo develops towards the anterior pole, this is of extreme importance in connection with the escape of the young insect from the egg. Eggs are frequently bedded with many others on a fixed base or buried in plant tissues, and, in such cases, it is essential that the young insect should escape head first by the only route available.

The act of fertilisation in many animals is directly associated with the act of mating, but, in insects, mating frequently takes place long before oviposition, and the insect egg is not fertilised by the spermatozoon until the moment before it is laid. In some cases months elapse between mating and oviposition—for instance, in the social wasp and humble-bee—while in other cases fertilised eggs are laid as much as three years after mating—for instance, by the queen honey-bee.

It is necessary, therefore, that the spermatozoa should be stored somewhere until they are required, and for this purpose there is an internal sac, the "spermatheca," to which they all make their way. Connected with this sac is a minute gland, which supplies a nourishing fluid to the spermatozoa, and thus they are kept alive until they are required.

In many insects the female controls the escape of the spermatozoa from the spermatheca, so that she can permit them to pass out when she is laying an egg, or she can lay an

unfertilised egg. In the latter case, the egg, if it develops, does so parthenogenetically.

Fabre made most interesting observations on the Mason-bee (*Chalicodoma*) and experiments upon the Bramble-bee (*Osmia*), which showed conclusively that the mother decides the sex of the egg, although he did not regard the male eggs as being without spermatozoa: a fact which has been proved by microscopical examination in the case of the honey-bee.

More will be found upon this subject of the determination of sex in Chapter VII.

But all insects do not lay eggs, some producing living young: the egg passing through its embryology within the body of the mother and hatching there, the young being extruded. This phenomenon, known as "viviparity," has been observed in at least six of the Orders of insects: in certain Earwigs and Cockroaches, Mayflies, Bugs, Beetles, Moths, and Flies. Amongst the bugs we find it as a normal process in the Aphides or Plant-lice, and also in certain groups of flies, but otherwise it is found only in odd species.

In the aphides, all the summer generations are viviparous, and as no males appear during that period, the viviparous generations are all the product of parthenogenetic females. In the autumn males are produced, and the females each lay one fertilised egg (*see* Chapter II).

With a few exceptions, all other cases of viviparity are associated with normal sexual reproduction, and in most cases the young is extruded immediately after hatching in the uterus of the mother. Among the flies, however, in the group Pupipara and in certain others, such as the Tsetse-fly (*Glossina*), well known as the carrier of the germ of sleeping sickness, the young is nourished in the uterus of the mother, and does not appear until it is practically full grown and ready to become a pupa.

This is especially interesting, because, as we have already seen in a previous chapter, the higher insects, to which the flies belong, have developed a larval stage, which does not exist in the lower orders, by hatching out the

embryo in a very immature condition and making it the main feeding stage in the life-history. These flies, therefore, have apparently begun to suppress the larval stage, and the adults are taking over the feeding for the whole life-history.

As has already been mentioned, parthenogenetic reproduction is the development of the offspring without a spermatozoon having entered the egg, and it is a very widespread phenomenon among the insects, having been recorded in at least six of the Orders. Amongst the moths it only occurs occasionally, and is apparently not normal in any species, although Pictet has recently produced a paper in which he states that it is frequent in the Vapourer Moth (*Orgyia antiqua*) and a few others (21). It is of not infrequent occurrence in the Silkworm (*Bombyx mori*), and advantage is taken of it in this case to rejuvenate worn-out strains, and it is said to be very effective for this purpose.

In a few other moths it has been recorded, such as the Oak-eggar (*Lasiocampa quercus*)

and the Gipsy Moth (*Ocneria dispar*), but it is of no importance in any of these.

In many insects it is a regular occurrence, and, as has already been mentioned, it is associated with the production of the male sex in bees and wasps. In certain groups it is of special interest, because in them the males appear to be dying out. For instance, in the sawflies, in some species the males are very rare. In the large Larch Sawfly (*Nematus erichsonii*), Gordon Hewitt collected cocoons to the number of 6181 in three years. These produced 6158 females and only twenty-three males. In certain other species males are unknown, which may mean that they have entirely disappeared.

Again, in the large group of parasitic wasps, there are a number of species in which the males are either rare or unknown, and in some cases amongst them—for instance, in some of the gall-wasps—a generation of sexual individuals alternates regularly with a generation of parthenogenetic females. These two generations are often so unlike one another

that, until the facts as to their relationship were discovered, they were described as distinct species, and in many cases as belonging to different genera. An illustration may help to make this clear.

In the spring, when the flower peduncles of the oak are developing and the leaf-buds are just beginning to open, a minute gall-wasp known as *Neuroterus lenticularis* appears, and, piercing the flower peduncles and the leaf-buds with its ovipositor, it inserts an egg into each hole. No males appear, so that these Neuroterus are all parthenogenetic. In due course small globular galls appear where the punctures were made, green, with reddish marks upon them. In the middle of each gall is the growing grub of the Wasp, which is full grown some time in May and becomes a pupa. In June, a gall-wasp bites its way out of the gall, and it is so different from its parent that it was described as a different species belonging to a different genus, and named *Spathegaster baccarum*. This generation has two sexes, and the females, after

mating, pierce the oak leaves and lay their eggs in them, one in each puncture. The grub hatches in a week or two, and in about three weeks galls begin to develop, but galls very different from those produced by the previous generation.

These Spathegaster galls are flat and button-like, and reach their full development in a few weeks. When the oak leaves fall in the autumn, these galls remain attached to them, and the gall-wasps issue from them in the following March, gall-wasps which are unlike their parents, but identical with their parthenogenetic grandparent.

One further point of interest in connection with this type of reproduction is that some of the parthenogenetic females lay only male-producing eggs, while others lay only female-producing ones. Alternation of generations also occurs in the aphides or "plant-lice," as has already been mentioned, the parthenogenetic generations succeeding one another all through the summer period, and being succeeded by a single sexual generation, which in

appearance does not differ very considerably from the parthenogenetic type. This condition of a species in which it produces alternating generations appears to be a stage in the process of elimination of males, since other gall-wasps seem to have completely suppressed the sexual generation and only reproduce parthenogenetically. We see therefore that the gall-wasps appear to be following a line of evolution parallel to that seen in the saw-flies already mentioned.

One peculiar form of parthenogenesis exists in which immature individuals develop the power of reproduction. This is known as "pædogenesis," and has only been observed in the larvæ and pupæ of certain flies and in one beetle, although a somewhat similar phenomenon occurs in termites, or so-called "white ants," where individuals externally immature become capable of laying eggs (*see* Chapter VII).

Pædogenesis was discovered as long ago as 1862 in the larvæ of a small gall-midge, known as *Miastor*, which occurs commonly under the

damp bark of decaying trees. The fly lays a few large eggs, and the larva feeds and grows in the usual way, but it does not pupate, because, while it is growing, seven to thirty young larvæ begin to develop within it. These feed upon the internal organs of the mother larva, which they destroy, and, thereupon, they bite their way out through the body-wall and feed in the normal manner on the decaying wood. These larvæ again reproduce in the same manner, and this continues for several generations before the cycle comes to an end and the larvæ pupate, the pupæ later hatching into male and female flies. The females, after mating again, commence the pædogenetic cycle by laying the large eggs.

Here again, therefore, we have one sexual generation alternating with a series of parthenogenetic ones.

One very interesting form of reproduction which occurs in certain families of the parasitic wasps is that in which one egg gives rise to a number of offspring, a process known as

"polyembryony." It is by no means peculiar to insects, as it occurs in the *Polyzoa*, or "moss animals," Colonial creatures, some of which resemble seaweeds in appearance, and it also occurs normally in one of the Armadillos, known as *Tatusia novem-cincta*, where four embryos develop from a single egg. Abnormally it occurs in many mammals, and what are known as "identical twins" in the human species are cases of polyembryony, one egg having produced two embryos. It was first discovered in insects by Paul Marchal, the well-known French entomologist, who found it in a minute parasitic Wasp which is parasitic upon the caterpillars of a small moth (19).

The parasite is known as *Encyrtus fuscicollis*, and the host is a species of *Hyponomeuta* (*Yponomeuta*).

The moth, known as the "small ermine," whose caterpillars are referred to in Chapter VIII, lays its eggs all together in a layer on the twigs of Spindle Tree (*Euonymus*), and covers them with a transparent varnish to

protect them from cold and damp during the winter months.

The Encyrtus lays its eggs in the moth eggs, not more than one in each, and the egg of the parasite remains unhatched and almost without developing all through the winter, although the host larva hatches out in the autumn. The caterpillars, however, remain under the varnish and hibernate there, not breaking their way out until the following February, when they wait for the buds to break, and then, for the first time, they commence to feed. At this time rapid development begins in the Encyrtus egg, which gives rise to a series of embryos extending in the blood-space of the caterpillar, and, as the latter forms a defensive layer of cells round these, they become joined in a long chain consisting of as many as 180 embryos. The caterpillars are full grown about the end of June, and, at this time, the parasitic larvæ break out of the enclosing sheath into the general blood-space of the host, where, at first, they feed upon the blood and later eat up the tissues, finally

pupating in the empty skin of the devoured caterpillar.

Since Marchal's discovery, other wasps related to the above have been discovered exhibiting the same phenomenon, most of the hosts being Caterpillars of different moths, although one has been found in the larvæ of the Hessian fly, a serious pest to wheat, barley, and rye in many parts of the world, and others attack certain other insects.

In many cases the embryos which develop are of two kinds, which have been called " sexual " and " asexual," although the latter appear to be only unsuccessful embryos, which later perish and are used as food for the others.

This is such an interesting subject that it is worth inquiring further into it, and one question seems to present itself: What happens to make an egg give rise to more than one embryo? An egg consists of a single cell, and its chief contents are a central body or nucleus and the surrounding protoplasm. When fertilisation takes place, the

nucleus of the spermatozoon enters and fuses with that of the egg, which, however, first throws off some of its substance, which forms the "polar bodies."

If fertilisation does not take place, as in the case of the parthenogenetic eggs, one of these polar bodies returns and rejoins itself to the egg nucleus, thus taking the place of the male nucleus. The egg now begins to divide; its nucleus divides into two, and they move apart, and the original cell becomes divided into two, each nucleus claiming dominion, as it were, over half the protoplasm of the original cell. Now a further division takes place, each of the two nuclei dividing, and the two cells then become four. Next there is an eight-cell stage, and so the embryo continues to develop by cell division.

It has been discovered that, if an egg in about the four-cell or eight-cell stage can be shaken to pieces without killing it, each piece will continue to develop—not as if it were one-quarter or one-eighth of the original egg, but as if it were the whole egg, so that four

or eight embryos may thus be artificially produced from a single egg. This has been actually done with the eggs of certain sea-urchins. This artificial polyembryony does not appear, at first sight, to have anything to do with the natural process, because there is no evidence that the parasitic eggs get shaken up within the hosts, but there is reason to believe that they undergo something equivalent to a shaking, and it was Marchal who suggested this. In such a case as that of Encyrtus already described, it will be noticed that, although the host caterpillar hatches in the autumn, it remains passive without feeding until the spring, and, during all this time, the parasite egg has also remained almost stagnant. When the caterpillar makes its way out and begins to feed, the internal conditions are completely changed for the parasite, and Marchal describes this as a change in osmotic pressure which pulls or shakes asunder the cells of the developing embryo of the parasite. This seems a reasonable explanation, but it does not appear to be quite the whole story.

In other words, a normal egg under similar conditions would probably not respond to these changes in osmotic pressure in the same way, and studies of the eggs of the polyembryonic species in their early stages seem to show that they are not quite normal. In the first place, in the normal egg the polar nuclei, already mentioned, quickly disintegrate, whereas in these eggs the polar nuclei divide and form a polar cap which spreads round and ultimately encloses the other cells of the egg. Also the egg nucleus, instead of remaining in the middle of the egg and dividing into two, retires away from the polar nuclei towards the posterior end of the egg, and divides into two, and there two cells are formed. One of these receives a nucleus-like body which suddenly develops by the running together of a number of minute dark particles in the protoplasm. This body, known as the "oosoma," interferes with the division of the cell, which it enters, and differentiates all its descendants from those of the other cell. Thus at this early stage there is what might

be described as discord in the egg, such as does not occur normally, and one of the groups of cells seems to grow amongst and break up the other group into separate bundles, or even into separate cells, which, thus cut off from their sisters, proceed on their own account to produce embryos. It seems therefore that the actual cause of the break up of the original embryo is within the egg, although the stimulus may come from without and may be the change in osmotic pressure.

This is a very superficial account of what happens, and although it is, we hope, correct as a general statement, it has omitted all sorts of details which are of considerable importance.

The removal of the gonads (testes or ovaries) has been carried out in a number of cases upon young caterpillars and on crickets, and the results have been rather unexpected.

The operation of castration in mammals has the effect of stopping the normal development of secondary sexual characters, while the introduction of an ovary in place of the excised testes or of a testis in place of the

ovaries, causes to appear characters associated with the female and male respectively.

Castration in the case of the insect, on the other hand, at any rate so far as it has been practised, gives different results. The individual continues to develop its secondary sexual characters in a normal manner. Even the introduction of the gonad of the opposite sex makes no difference.

It has been suggested that too little work has been done upon this subject in connection with insects to justify conclusions being drawn, but Goldschmidt, to whose book reference has already been made at the beginning of this chapter, concludes that there is a fundamental difference between the two groups; that in the mammals the gonads themselves produce a secretion which stimulates the production of the secondary sexual characters, whereas in the insects the sex has been determined at the time the egg received the nucleus of the spermatozoon, and that the sex secretion or hormone has been distributed to each cell from the commencement of cell-division (9).

On the other hand, what has been called " parasitic castration " has given results which do not appear to agree with those obtained by artificial castration.

Perhaps the best case among insects is where a parasite, known as Stylops, attacks certain bees of the genus Andrena. The life-history of the parasite is as follows. The young larva first sees the light on the body of a bee, where it holds on to the hairs by means of three claws on each foot. This peculiarity of three claws, which it shares with a few other young larvæ of unrelated insects, has given it the name of the triungulin larva.

As many as several thousand triungulins may emerge on the surface of a single bee, and their object is to disperse to other bees. This they presumably do by alighting upon flowers, which the bee visits in search of nectar, and waiting for other bees to arrive. Possibly also those on male bees transfer themselves to females at the time of mating, because the triungulin's future depends upon its reaching a bee larva.

The female bee builds her cells in underground galleries, storing each cell with a mixture of pollen and honey, and on this food material she lays an egg. This moment is the triungulin's chance, and it leaves the bee and is sealed up in the cell. The bee grub hatches out, feeds and grows, and the small parasite bores its way into it, and immediately casts its skin and changes its form, becoming a legless grub. It now apparently feeds through its thin skin, absorbing the blood of its host, but doing no damage to any of the internal organs. It is full grown by the time the grub changes to a pupa, and then it bores its way out between two of the body segments of its host, and there it remains fixed, with only a small part protruding, and becomes a pupa. When the bee emerges from her cell, the male Stylops, as a minute-winged insect, escapes from its pupal skin and flies away, but the female Stylops remains grub-like in form, and so incompletely developed that, until comparatively recently, it was not known whether it was her

head or her tail which protruded from the bee. In this position, the male finds her and mates with her, the spermatozoa being released into the large brood-pouch which opens near the anterior (exposed) end, and somehow finding the eggs which apparently have escaped into the general body cavity by the breaking down of the ovaries. The eggs hatch in the body of the mother, who is therefore viviparous, and the larvæ ultimately escape on to the back of the host through the brood-pouch, to seek new hosts for themselves.

The effects of these parasites upon their hosts are such that the females acquire certain male characters, while some female characters appear in the males, results which apparently contradict those obtained by artificial castration. It should, however, be mentioned that although this case is usually referred to as one of parasitic castration, there is no evidence that the females are rendered sterile, while there is evidence that the males retain the testes and produce spermatozoa (24).

CHAPTER V

USEFUL INSECTS

THE vast majority of insects might be regarded as neither useful nor harmful to mankind, and we are accustomed to regard ourselves as the beings for whose delectation or punishment all other living things have been created.

All insects, however, like all other living things, have their place in Nature, and we are not justified in regarding anything as useless from that point of view.

This will probably cause many people to ask, " Well, what use has such an insect as the flea ? " The flea is primarily a scavenger, its larvæ feeding upon decaying organic refuse. Its parasitic habit, by which, in its adult stage, it sucks the blood of animals and birds, although of no use to us, is of the greatest

use to the germs of plague, since these germs pass from rat to rat and from rat to man through the agency of the rat flea, which sucks the blood infected with the germs from one host and regurgitates some of it with the germs into another.

We are therefore in this chapter limiting ourselves to insects which are of some use to mankind, either by reason of a general utility, or because we have been able to turn to our advantage their ordinary habits.

In the first place, those insects which burrow in the ground are of general use because the soil, in order to remain sweet and useful to plant life, requires constant aeration and cultivation. Earth-worms are the chief cultivators of the soil, and Darwin, in his fascinating book on "Vegetable Mould and Earthworms," states that, by working out the actual weight of castings thrown up by them upon a square yard of ground in a field at Down, Kent, he found they brought up from 7½ to 16 tons of soil per acre in the course of a year (4).

No insect equals the earth-worm as a cultivator of the soil, but ants and termites remove large quantities of sub-soil and spread it upon the surface in the construction of their nests, and, in this respect, these insects, which are serious pests in many ways, are useful.

Many insects are useful as scavengers, eating up decaying organic matter and, by digesting it, reducing it to a form more immediately usable by the vegetation.

A number of insects lay their eggs upon dead animals, and the larvæ which hatch from these feed upon the decaying flesh, the adult insects themselves often feeding upon the same material. During the summer, the dead body of a bird or animal is very soon the centre of attraction for a number of "burying beetles," some of which are bedecked in suitable black, while others are adorned with bands of bright yellow, orange, or red. But these beetles have some work to do before they begin to lay their eggs upon the corpse. On arrival, they quickly disappear beneath the body, and begin to dig away the earth, and this work continues

until the corpse has been lowered into a grave, which closes in over the body by the falling in of the 'sides. The grave is some inches deep, and the beetles "prepare" the body when it has reached the required depth.

The preparation consists in compressing the remains into the smallest possible space, and in stripping off the fur or most of the feathers, and, when this work has been completed, the female beetle lays her eggs, and the larvæ, and to some extent the beetles, feed upon the putrefying material.

Fabre has written a very interesting account of the behaviour of these beetles (5). He made a number of experiments with them, by which he found that they would move a body from a spot where a brick prevented its burial to a more suitable place, discovered by reconnoitring on the part of the males. He found that if a body were tied up so that it could not descend into the grave by its own weight, the beetles would cut the bonds, and so lower it to the ground, and he showed that these and other acts, which at first sight

appeared to show intelligence or the power to think out a situation, were merely due to instincts which had probably been in the ancestors for thousands of generations, and which were necessary to enable the beetles to overcome natural dfficulties which are of frequent occurrence (*see* Chapter II, " Race Memory ").

There are many other insects which are carrion-feeders, and some of these, from their appearance, we would never suspect of such habits. For instance, the beautiful " Purple Emperor " Butterflies (*Apatura iris*), and several others, come readily to horse-dung on the roads and suck the fluids from it, and all butterfly collectors know the attraction which a piece of putrefying meat has for butterflies.

Ants readily devour small animals and birds, picking the flesh from the bones and leaving a clean skeleton.

Flies, for instance, the common Blowfly (*Calliphora erythrocephala*), quickly discover a corpse, and lay their long white eggs in the sides of the mouth, in the nostrils and corners

of the eyes, and on the bare patches of skin under the legs. In a few days the white maggots hatch, and by vomiting a digestive fluid, dissolve the solid parts and drink up the liquid. The fly makes no attempt to bury the corpse, but prefers to lay her eggs on the under-side, or at least out of the direct sunlight.

A large group of beetles feed upon dung, and provide it as food for their larvæ.

Fabre and others have investigated the habits of a number of these dung-beetles, and we may with advantage mention a few details. Some of the species merely feed in the masses of dung where they lie, and lay their eggs there. Others, again, dig deep perpendicular burrows beneath the dung for the reception of their eggs and of food for the larvæ when they hatch. In the preparation of these burrows, the male and female often work together, the female sinking the shaft and the male carrying up the earth which has to be removed.

The dung is then carried down, and, when a sufficient amount is there, the male leaves

the female, and either seeks another mate or retires into seclusion. The mother alone now undertakes a long preparation of the material, which is made into a large spherical mass and apparently allowed to mature under her watchful eye, since she crawls round it and over it, stroking it with her feet and antennæ and, by some obscure sense, knowing what is taking place inside.

Once it has reached the right condition, she breaks off about a third or a quarter of it, and, with this, makes a new sphere or ovoid, finally hollowing out a small cup and laying an egg in it, and then, very carefully, enclosing the egg by constructing a thin wall over it. She makes altogether three or four of these bodies, laying an egg in each, and in this way she uses up nearly all of the stored material.

Having completed this work, she now enters upon a long period of careful nursing, moving between and over the precious morsels and keeping them smooth and clean. About three or four months after the commencement of the work, the mother comes out of her nursery

with her young, and the family breaks up to feed, the aged mother probably dying when winter comes, while the young bury themselves in cells in the ground and await the spring.

Other dung beetles make their nurseries at a distance from the source of the food supply, and these make up the material into a ball and roll it to some suitable spot, where a shaft is sunk and the mass is lowered into an underground chamber. But this difference in habit is associated with a further difference. The mother in this case makes up the whole mass once and for all, and lays an egg in it as in the previous case. She does not mount guard over it, but at once deserts it to repeat the process elsewhere.

This, again, is associated with further differences. Such a mass of dung contains innumerable spores of fungi, which, unrestrained, grow in the dark and damp conditions of the cell, soon changing the smooth surface of the ball into a rough one full of cracks. This never occurs in those cases where the mother remains with her developing eggs, since she is per-

petually brushing and licking the surface. Fabre found that, in such a case, if he made cuts in the surface or exposed the egg or young larva, the mother quickly repaired the damage, whereas where the ball is left unattended, the larva itself repairs any damage by plastering the cut with its thick excreta, and this forms a hard, cement-like stopping in the opening (6).

All these dung workers are cultivators of the soil as well as scavengers, as they break down the material into simpler form, and thus make it more readily available for the use of plants.

Another way in which insects are of the greatest use to man is as flower pollinators.

They transfer the pollen from the stamens to the pistil, either of the same flower or, more usually, to that of another, and thus cause the fertilisation of the plant egg, since the pollen grain contains the nucleus equivalent to that of the spermatozoon, while the plant ovary contains the equivalents of the eggs (*see* Chapter IV, p. 87). The plants

provide pollen and nectar as food and drink for the insects, and, in return, the insects carry out the pollination, and thus the visits to flowers are of advantage to both parties.

One might almost imagine that both parties were actually conscious of this, because flowers have undoubtedly become adapted to insects, and insects have become modified in connection with their visits to flowers. Although a great many insects of different Orders visit flowers, the bees are by far the most important pollinators, and, after them, certain groups of flies.

With regard to the adaptations of insects, in groups where some species frequent flowers, while others do not, the flower-visitors usually have more hairy mouth-parts than the others, an adaptation for pollen-gathering, and many plants reply to these pollen-eaters by providing either an extra supply of pollen or even a different kind of pollen grain as food.

These pollen-eaters crawl over the flowers and become smothered in the pollen, which adheres to their bodies, and thus is liable

to be carried over the sticky stigma of the ovary.

The mouth-parts of the Syrphid flies, known as "Hoverers," are used for rubbing the pollen grains apart, so that the insect can swallow them, and, although they are not very different from those of many other flies, the two large flaps, or "labellæ," at the apex of the proboscis or lower lip are well adapted for this purpose.

The bodies of the bees have many branched hairs upon them, more on the head and mid-body than behind, and these hairs seem to be admirably adapted for catching the pollen grains as the insect rubs past the anthers. Again, in many insects the mouth parts are lengthened out, enabling the owner to reach the nectaries at the base of the corolla tube in trumpet-shaped flowers. For instance, the delicate proboscis of butterflies and moths is adapted for this purpose, and the honey-bee and humble-bee and some others also have mouth-parts lengthened for the same purpose.

In some cases the adaptation of the insect has been very elaborate. For instance, the

Yucca moths, of which there are several species, lay their eggs in the ovaries of the flowers of the Yucca plant. It is essential for the life of the caterpillar that the ovary should develop into a pod, as it is in the pod that the caterpillar feeds. The Yucca flower is not capable of pollinating itself, nor is it constructed for pollination by visiting insects. But the Yucca moth has a special tentacle projecting from each of her accessary jaws or maxillæ, and, with these tentacles, she deliberately gathers a mass of pollen and inserts it into the upper part of the stigma. The work is done very carefully and occupies sometimes as much as half a minute.

In the process of time the adaptation between insect and plant has become more and more perfect and, on the plant side, two lines of evolution are recognisable. Some plants seem to have decided that their advantage lies in getting pollinated as many flowers as possible by any kind of insect which may arrive, and, to this end, they have crowded their flowers into heads. For instance, in the

daisy and all its relations of the Family Compositæ, although the head looks like one flower, it includes a large number. In the same way the Hemlock, Fennel and Fool's-parsley and most of the Family Umbelliferæ have formed loose heads of flowers, and many other plants have done the same thing. They have thus (1) saved material in the construction of each flower, (2) attained advertisement by crowding the flowers, and (3) made them capable of pollination by almost any visiting insect which walks over them.

This packing into heads has also affected the form of the flowers. In the daisy, for instance, the yellow flowers forming the centre are regular in form, whereas the marginal flowers have one side projecting out to form the large white ray, and they are irregular. In the same way, the flowers of the hemlock family have mostly become irregular in shape because of the crowding.

With regard to the single flowers, the simpler ones are regular like the buttercup, and are capable of pollination by a variety of insects,

but there has been a tendency in those plants which have not gone in for crowding to specialise their flowers to suit certain insects, and most of their flowers have become highly irregular in form. Many have provided landing-stages for the visitors—for instance, the sage and other species of the Dead-nettle family, and many have developed extraordinary contrivances for ensuring that the insect touches the stamens and the stigma.

This specialisation has, in many cases, led to the plants becoming dependent upon one type of insect for pollination. For instance, many flowers are only capable of pollination by the humble-bee, and among them the Monkshood (*Aconitum napellus*).

In such cases it is obvious that the range of the plant is limited by the range of the insect. Should anything happen to wipe out the humble-bee in any district, the monkshood would set no seed there.

Although amongst the higher animals inbreeding has bad effects—and that is why a man may not marry his grandmother—among

insects it is a frequent occurrence; but plants for the most part avoid it, or only rely upon it as a last resource. Most plants ripen the stamens before the pistil, and some the pistil before the stamens, so that an insect visiting a flower in search of nectar will either get dusted with pollen from the ripe anthers, or will be rubbed by the sticky stigma in its search for the pollen grains.

In some of these plants one or two stamens are kept in reserve, so that, in case an insect should fail to bring the necessary pollen to the stigmas, these stamens bend over and shed their pollen, and thus secure the production of seed.

In connection with the subject of insects and flowers, there is one other special case which should be mentioned. We have seen that many plants crowd their flowers, and thus, for the most part, make them capable of pollination by many insects in an economical manner. One group of plants, the figs, has crowded its flowers into heads, but the heads have caved in, so that the flowers are

enclosed within the base or thalamus. This has made them incapable of pollination by all insects except one small group, belonging to the parasitic wasps, known as Blastophaga or, more commonly, "fig insects," and, as these insects cannot pass through their life cycle without the figs, the two types of life are entirely dependent upon one another.

There are over one hundred species of wild figs, and they are all inhabited by fig insects, and apparently different species of figs are inhabited by different species of fig insects.

The ordinary wild fig or "caprifig" is common in the Mediterranean region. Its inflorescence, the inverted thalamus, contains three kinds of flowers, male, female, and gall-flowers, the latter being imperfect female flowers which never develop, but which might almost be described as being specially provided for the fig insects, which lay their eggs in the ovaries. There are usually three crops of flowers in the season; the first of these produces male and gall-flowers, the former developing so slowly that they are only pro-

ducing their pollen when the second crop, consisting of male, female, and gall-flowers, is produced, so that the male flowers of the first crop provide the pollen which the fig insects carry from that crop to the second and pollinate the female flowers. The third crop again produces the same types as the first, so that, all through the season, there are flowers suitable for the fig insects.

The edible fig is in some way descended from the caprifig, and, except in rare cases, produces no male flowers, the whole receptacle being filled with female flowers. In most of the varieties of edible figs, imperfect female flowers occur, which are either female flowers which have degenerated, or are gall-flowers which have partially regained their female characters. Most of the edible figs have acquired the power of ripening—that is, becoming sweet and succulent—without producing fertile seeds, and therefore without fertilisation, a phenomenon almost, if not quite, unique among plants. Some, however, will not ripen without producing fertile seeds

—that is, they require fertilisation. This is achieved by what is called "caprification," which consists in cutting off the figs from the wild tree, stringing them together in fours on a long straw or reed, and suspending this amongst the branches of the edible fig tree. The fig insects then pass into the edible figs and pollinate the female flowers.

Thus has man taken advantage of the habits of these minute insects. Man has also taken advantage of the habits of the honey-bee, which he has domesticated and taught to rear its broods and to store up its honey under special conditions in hives. A few points in the life-history are discussed in Chapter VII, but see the bibliography at the end of the book Nos. 25 and 20.

The "silkworm" is another insect which has been cultivated for centuries, and the most important species, *Bombyx mori*, does not now occur in the wild state. The cultivation of the silkworm, or "sericulture," has been dealt with in a number of works (17), (18).

The natural products of some of the scale insects are utilised by man. The lac insect provides a material, consisting chiefly of resin, which provides us with spirit varnish, furniture polish, and various other useful commodities. It also provides a red dye which was at one time largely used in the East for dying silk and wool. The insect feeds upon the sap of various trees, piercing the bark with its long, delicate mouth-parts, and it is cultivated to the extent of being transferred from one wild tree to another, infected twigs being hung up among the branches. The female, once she has settled down to feed, never leaves the spot.

The young nymphs hatch out and disperse, seeking young juicy twigs, where they in turn settle down and begin to exude a transparent varnish, which covers them, and, as they crowd together, a layer of varnish is formed which surrounds the twig. A month or more after settling down, the nymphs become adults, and the males, some winged and some wingless, escape from the varnish and mate with

the females, which, two or three months later, lay their eggs and die. The exudations of the crowded individuals run together and form a thick layer round the twig, but this material does not contain the dye, which is only developed within the bodies of the females (14).

For commercial purposes the encrusted twigs, known as " stick-lac," are gathered, and the incrustation is stripped off and crushed, when it becomes " seed-lac." This is melted and filtered and allowed to fall into shallow pans, when it becomes the " shell-lac " of commerce.

The cochineal insect is another " scale " which used to be largely cultivated in Mexico on wild cactus for the sake of the dye which develops in the body of the female, but its use has now been largely superseded by the aniline dyes.

The " manna " upon which the children of Israel fed was probably the excretion of one of these scale insects, and is still known as " man " and used as food by the Arabs.

Certain insects which by their excretions or secretions cause galls to form on various

plants are useful, in that the galls themselves are of commercial importance and are used in the preparation of ink; mixed with chlorate of potash, powdered "nut galls" produce an explosive mixture used as a blasting powder, and a preparation of galls has been used in dyeing.

Many other insects are directly or indirectly of use, and the exploitation of parasitic insects for the purpose of controlling insect pests, an idea which has only been developed comparatively recently, will be dealt with in the chapter on Insect Parasitism.

CHAPTER VI

INSECT PARASITISM

THE literal meaning of the term " parasite " is " one who eats at the table of another," and yet the word brings to our minds such unpleasant things as fleas, bugs, and lice, which we certainly call parasites. We might therefore define the word anew as meaning one who lives at the expense of another. If, however, we follow out this definition to a logical end, we should have to describe a caterpillar as parasitic upon a plant, and ourselves as parasitic of oxen and sheep. The fact is that between the complete dependence of one species upon another and the association of two species to their mutual advantage there are very many intermediate stages, so that it is best to use the term rather vaguely.

Amongst insects, parasitism has arisen in

some nine or ten Orders out of a total of about twenty.

Amongst the Exopterygota, four Orders include them. There is one small Family related to the cockroaches, the Hemimeridæ, parasitic upon rodents in West Africa.

The bed-bug is a representative of the Rhynchota or Bug Family, and the biting and sucking lice belong to the Order Anoplura, all the members of which are parasites.

Among the Endopterygota about seven Orders include parasites, and of these, two are entirely parasitic.

A large number of the parasites are associated with the higher animals, and most of these suck the blood of their host. These are of extreme importance, because, although many of them are themselves injurious to the health of the hosts, others transmit the germs of disease from one individual to another, many such germs being only transmitted by this means. Thus, in the absence of lice, and perhaps bed-bugs, typhus fever cannot pass from one person to another, typhus epidemics

being dependent upon the presence of the insects. Malaria and yellow fever are in the same category, being only distributed by certain kinds of mosquitoes.

In this chapter, however, we are only dealing with insects which are parasitic upon other insects, and we find that all these belong to three or four Orders of the higher group, the Endopterygota. All the important parasites belong to the three Orders Coleoptera or beetles, Hymenoptera (Ant, Bees, etc.), and Diptera or Flies, and of these, the first contains a very small percentage belonging to about four families.

The beetles apparently only parasitise in the Orders Orthoptera and Hymenoptera, while the other two Orders are almost unrestricted in their range, though it is interesting to note that the Diptera are scarcely attacked by any parasites, while the Hymenoptera are not only attacked by beetle and fly parasites, but largely make war upon themselves.

Wheeler, in his book upon "Social Life

among the Insects," speaks of a tendency to co-operation and mutual aid as being "a pervasive and fundamental innate peculiarity of organisms," and as existing side by side with a struggle for existence between them (27). If this is so, we might describe parasitism as having arisen through less scrupulous species taking advantage of the others, the struggle for existence in them being stronger than the idea of mutual aid.

With this idea in mind, a few examples of associated organisms might be useful.

The hind-gut of many insects swarms with minute forms of life belonging to the protozoa and bacteria, and we should at first sight regard them as being parasites, since they are feeding at the expense of the insect. But it has been shown in certain cases that they are actually of use to the insect, because they break down some of the indigestible materials swallowed and make them capable of absorption by the insect. Thus it has been stated that the protozoa in the gut of certain termites break down the chips of wood which have

been swallowed and produce sugars so that the termite and its " inhabitants " are living together to their mutual advantage.

In certain bugs, including the well-known " Cotton Stainers " (*Dysdercus*) and the " Chinch Bug " (*Blissus leucopterus*), certain pockets extending from the mid-gut are always found to be full of bacteria, at first sight suggesting disease. An examination of the nymph just emerged from the egg shows that the " disease " is hereditary, and apparently it does no harm to the insect. It has been suggested that the bacteria, in return for food and lodging, act as police for the bug and prevent other and dangerous bacteria from developing.

In other bugs—for instance, the aphides or plant lice—a structure occurs which by some has been regarded as a special excretory organ, but by others is stated to be a special sac containing bacteria or protozoa, which are of use to the insects as absorbers of waste products or of excess food materials. Here again these micro-organisms pass into the eggs and

so are transmitted from generation to generation.

But it is not only between insects and internal micro-organisms that this relationship exists. Many insects are associated with other insects for the benefit of both. In the nests of the common wasps and humble-bees are almost always the larvæ of certain flies known as *Volucella*. The flies themselves are interesting, because they resemble in general appearance the wasp or humble-bee in whose nest they lay their eggs, and it was at one time suggested that the object of their disguise was to enable them to enter the nest without being recognised by the owners. This explanation fails in view of the fact that wasps and bees recognise introduced strangers of their own species probably by smell, it having been suggested that all members of a community become tainted with the smell of the nest. Among bee-keepers it is, or was, the custom, when uniting two small colonies to make a strong one, to dust all the bees with flour. The object of this is to make the bees

unable to recognise one another, the nest smell probably being overwhelmed by the smell of the flour. By the time they have cleaned one another, all the bees have acquired a common smell, and consequently no fighting ensues.

It is therefore more probable that the resemblance between the Volucella and its host has been fortuitous to begin with, and that it has been perfected by natural selection, the elimination of those individuals less like the wasps and bees by certain insectivorous birds which will attack flies but not wasps and bees.

The Volucella larvæ are scavengers in the nests, feeding upon refuse and upon dead or injured wasp or bee grubs. Fabre placed some of the fly larvæ in a box with bee grubs, and he found that they died of starvation. If, however, he injured the bee grubs, the Volucella immediately attacked and devoured them. In the nests it is quite clear that they wander about at will, even pushing their way into cells containing grubs and pushing the

nurse wasps and bees out of the way without being interfered with.

The above is a case in which the relationship is obligatory, in that one of the insects is dependent upon the other—that is, the wasp can get on without the Volucella, but the fly, in order to reproduce, must find the wasp.

There are, however, innumerable cases in which two species may be able to live apart although they benefit one another when associated. For instance, ants and aphides are mostly non-obligatory associates, and certain slave-making ants can get on quite well without their slaves, being equally capable of looking after themselves (*see* Chapter VIII). We see therefore that Volucella is the first stage in the direction of parasitism, and further stages will be found in the chapter just referred to in the case of other slave-makers among the ants which have become so helpless that they can neither make their own nests, rear their broods, nor feed themselves.

Where both parties to the association benefit, we cannot use the term parasite with regard

to either, but the next stage, illustrated by the more or less helpless slave-makers, develops rapidly into one species making use of the other without giving anything in return, and this quickly develops into the killing out of the host.

Such a case is illustrated by *Anergates* among the ants (*see* Chapter VIII), but the so-called "cuckoo-bees" also provide excellent examples. The solitary bees build cells, which they store with pollen and honey, and in each of which they lay an egg. The cuckoo-bees are solitary bees, which, instead of building and storing cells for themselves, lay their eggs in the cells of other bees. The cuckoo-bee grub hatches before the other, and grows more rapidly, both grubs feeding upon the store of food; but, sooner or later, the cuckoo-bee grub attacks the other and eats it, in this way securing all the food material which was originally stored in the cell.

Here, then, we have a stage in which the host becomes the food of the parasite, and this is the type of relationship which is more

usually associated with the term parasitism, and of which there are very many, examples among insects. The vast majority of these are, to be found in the Order including the Ants, Bees, and Wasps, where a number of families are grouped together under the name Hymenoptera Parasitica, and, using the term "wasp" in a very general sense, we might call them all "parasitic wasps." The Order of Beetles is next in importance with regard to parasitic species, and one or two families of flies also include them.

In these cases where the parasite larva feeds upon its host, the parasite egg is either laid near or on the host, or, in the most perfect type of parasitism, in the host, and we distinguish as ectoparasites those which live outside the host, and as endoparasites those which live inside. In the case of the ectoparasites the larva is frequently very active before it settles down to feed, because sometimes it has to seek out its host, and almost always it has to look round and destroy any other parasites which may be on the spot.

Soon after the host is reached and the place has been cleared of competitors, the larva, in most cases, changes its form, and becomes more grub-like, and is said to undergo "hyper-metamorphosis."

To take a simple example: there is a small wasp known as the Five-spotted Sapyga, which is one of the Vespoids or True Wasps, and not one of the Hymenoptera Parasitica. It lays its eggs in the cells of certain bees, amongst these the Blue Osmia (*Osmia cœrulescens*). The egg is much smaller than that of the host, and hatches before it. The little grub has no legs, but is capable of rapid movement; moreover, along each side it bulges out, and is adapted for moving over the very wet honey paste stored by the bee and in the middle of which is set up the bee egg.

Having eaten any other Sapyga eggs or larvæ in the cell, the survivor seeks out the egg of the host and, mounting upon it, begins to feed. It takes eight days to finish its meal, at the end of which time it casts its skin and becomes a typical grub. In the meanwhile

the honey paste has dried up to such an extent that the grub is in no danger of sinking into it, and it now starts to feed upon it. As showing the close adaptation of the parasite to the host, experiments of changing the sapyga eggs into the cells of the Red Osmia (*Osmia rufa*) invariably resulted in the death of the parasite, the sole reason being that the food stored up by the Red Osmia for its larva is more pollen than honey. An addition of a little treacle or honey to the material made it quite suitable for the Sapyga.

In this case the hypermetamorphosis is slight, but in many cases it is much more marked. The large violet-coloured beetle often found on roadsides, which goes by the name of *Melöe,* has a precarious life-history, and, as an insurance against the risks, the female lays up to ten thousand eggs, which she places on or just below the surface of the soil amongst grassy vegetation.

The young which hatch out are elongate creatures with six long legs, each foot with three claws. When this type of larva was

first discovered it was thought to be a new and primitive insect, and it received the name "triungulinus." Since its relationships have become known, it is called the triungulin stage in the life-history.

Other related beetles having the same type of parasitic life have the same type of first stage larva, and it turns up again in the Order Strepsiptera, which is closely related to the beetles. The life-history of Stylops, one of the Strepsiptera, will be found in Chapter IV.

The Melöid triungulins run up the plants and get into flowers, where they await the arrival of bees, in the hope of being transported to their cells. Only certain bees, belonging to the genera Andrena and Anthophora, are of any use to the Melöid, and, unfortunately, the little creature cannot recognise them when they arrive; in fact, it does not even know enough entomology to distinguish bees from flies. Its instinct is to seize hold of the hairs of any hairy insect, and it is at this stage that a large proportion of the ten thousand

lives are lost. Having arrived at the bee's cell, it is probably brushed off the bee, while she is cleaning herself from the pollen she has collected, and, in the cell, the triungulin behaves in much the same way as the Sapyga already mentioned, except that the changes in the larval form are more marked.

With regard to the endoparasites, the females in some cases lay their eggs in or on the host, and in other cases upon the leaves, whence they enter the host, usually a caterpillar, by being swallowed with the food.

Now the internal insect parasite as a rule lives in the blood which fills all the space between the organs. It is not clear how some of the "submerged" larvæ breathe, as it is asserted by most authorities that insect blood has nothing to do with respiration, and therefore carries no supply of oxygen. Others of these larvæ attach themselves inside the skin of the host at the point where the egg was inserted by the mother, and open up communication between the outer air and their breathing system. Others, again, tap the air

supply in one of the main air-tubes within the host.

The precarious nature of the life of the parasite has already been illustrated by the case of Melöe, but there are many much more specialised cases.

There is a small chalcid wasp known as Perilampus which lays its eggs on the leaves in the haunts of certain caterpillars. The eggs give rise to a peculiar type of larva, known as a planidium, which is very active just after hatching, but soon attaches itself to the leaf by its tail end and sits up. It remains in this position sometimes for days, until some insect comes near it, when it sways about vigorously, making attempts to reach it. Like the Melöid triungulin, its chances of getting a caterpillar, and a suitable host at that, are not very great, but, if it succeeds, it penetrates into the blood-space, where it apparently does no harm. But its difficulties are not at an end. The caterpillar is of no use to it unless it becomes the host of a certain other parasite, either an ichneumon wasp or a tachinid fly,

the larvæ of which are also endoparasitic and are the true hosts of the Perilampus.

We have now learnt something of the difficulties in the life of a parasite, and we have seen that parasitism may have arisen out of a give-and-take relationship between two species. But there are other possible origins, and one has been put forward by Miss M. D. Haviland (11). She pointed out that a number of the Hymenoptera Parasitica are plant-feeders, the eggs being buried in the tissues of plants and the excretions or secretions of the larvæ causing the formation of galls, within which the larvæ feed. Such growths are frequently the home, not only of the producing larva, but also of other insect larvæ of related species, which save themselves the trouble of making galls by feeding within those of others. If some of these vegetable-feeders were to change their diet and prey upon the others, we should have a first step in parasitism, and it might be that the parasitic Hymenoptera arose in this way.

On the other hand, among the bees we can account for the origin of parasitism in another way. The cuckoo-bees, which have already been mentioned in this chapter, are remarkable for the fact that most of them bear a greater or less resemblance, not necessarily in appearance, but in structure, to their hosts. Wheeler (26) suggested that, in their case, they commenced by laying their eggs in the cells of their hard-working sisters, and that in this way they ultimately exterminated all the non-parasitic individuals in the species, and were then driven to using their other relations. In support of this view, it is rather interesting to observe that, in one group of these cuckoo-bees, the habit is not fully established, and that some individuals make their own cells, while others are parasites.

Enough has been said to show that the life of the parasite is not one of laziness, and if its origin, in the case of the bees, has been as Wheeler surmises, we must assume that the insects commenced the practice with the object of saving themselves trouble, a view

which might be taken of the other possible origins of the habits.

Sometimes it is the mother who goes to immense trouble in discovering a suitable host and in placing her egg upon it, and at other times the sins of the mothers are visited upon the children, and the larvæ have to work hard before they can feed. Again, there seems to be a certain limitation of suitable hosts, since vast numbers of individuals of one species of parasite attack individual hosts, and a species of host is liable to attack from numbers of species of parasites. For instance, more than seventy species of parasites attack the caterpillars of the Winter Moth (*Cheimatobia brumata*) in Europe. A single caterpillar of the Cabbage Moth (*Phytometra brassicæ*) has produced more than three thousand specimens of a small " Wasp " parasite.

Moreover, the tribulations of the parasite are not all recorded, since they themselves, as we have seen in one case already, are liable to be attacked by hyperparasites, which in turn may be attacked.

We can only conclude from the fact that they continue to exist in spite of all these things that parasitism is to be regarded as a paying business.

Man has, comparatively recently, begun to exploit the parasite business to his own ends. The idea was first suggested about 1850 by an American entomologist, Asa Fitch. He pointed out that we took various steps to destroy insects which damaged our crops and our forests, and which carried diseases to us and to our cattle, and that Nature, by means of the parasite, was working in the same direction. Our chief methods of control were the direct destruction of the pest species, either by poisoning it with arsenic, or by hand-collecting, or collecting by means of machines and killing the material collected. He showed that, in so doing, we were also destroying the parasites, which might be made use of if other steps were taken. No notice seems to have been taken of this, and the idea again appeared in France about 1872, when Decaux suggested a method of lessening

the damage to apple-blossom by the Apple-blossom Weevil (*Anthonomus pomorum*) by calling in the assistance of a minute "wasp parasite."

The beetle lays its eggs in the young flower-bud, and the larva hatches and feeds upon the stamens and pistil, causing the blossom to stop developing and to change to a rusty-red colour. The petals never open, so that these "capped" blossoms, as they are called, are very easily recognised on the plant.

Inside the cavity within the petals the larva changes to a pupa, and the beetle ultimately bites its way out and, during the summer, feeds upon the leaves of the tree. It had for long been the custom to gather these "capped" blossoms while the beetle was still in the larval or pupal stage and destroy them, and Decaux's suggestion was that, instead of doing that, they should be stored in boxes with wire-gauze covers, the mesh being too small for the beetles to escape from the boxes; the wasp parasite, which is very small, could escape through the gauze lids.

This method was not adopted until 1880, when an isolated area of orchard, containing about 800 trees, was dealt with. About 1,000,000 beetles were destroyed in the first year, and it was estimated that about 250,000 parasites escaped. The process was repeated in the following year, and after that, for about ten years, no serious damage was done in that area by the weevil.

Since that time the process has been carried out with success in other places, and it is undoubtedly a very important one for the control of insect pests.

However, most of the serious insect pests of a country are not native insects, but insects which have been introduced, generally accidentally, and, further, these pests are usually insects which are not pests in their native country. This fact led to the suggestion that they were probably controlled there by one or more parasites, and to the further suggestion that these parasites might be introduced into the country where the hosts had become pests.

One of the first attempts in this direction was with a view to controlling the "Fluted-" or "Cottony cushion-" scale (*Icerya purchasi*), which was a very serious pest of citrus in California. It was discovered that the pest was a native of Australia, and entomologists were sent there to study it. In 1888 a small Lady-bird Beetle (*Novius cardinalis*), which had been found feeding upon the scale, was shipped to California, where about 130 specimens arrived in January 1889. These were placed in an insectary and fed upon the scale, and they did so well that, by June, about 11,000 specimens had been distributed to 208 orchards. In nearly every case the colonisation was successful, and the effect upon the scales was almost magical: it disappeared so rapidly. The beetle has not become acclimatised, nor has it exterminated the scale, but it is always kept going in insectaries, and whenever there is an outbreak in any locality, a colony of the beetles is sent out there. Because of this success, the beetle has been introduced into New Zealand, Portugal, South

Africa, Egypt, the Hawaiian Islands—in fact almost everywhere that the fluted scale has been troublesome, and always with success.

Numerous other parasites have been introduced into different parts of the world where a pest has been giving trouble, but, although a number of these introduced parasites have been successful, the results have not always been so.

The difficulty is that the introduction of a parasite into a new country is a very different thing from the cultivation of a native parasite. All the living things in any locality together form a complex which represents the balance of Nature. Interference with any one species, or the introduction of a new one, upsets the balance, and Nature has to re-establish it again. The introduction of an insect which becomes a pest is evidence of the upset of the balance, and the introduction of its parasite, however it may affect the parasite, is certain to have some effect upon the complex. It is therefore important that the complex in its

relation to the pest species be studied before a new parasite is introduced, and this is scarcely possible, except in islands such as Hawaii, where it has been done with considerable success (13).

CHAPTER VII

SOCIAL LIFE AMONG THE INSECTS

THE majority of insects are "solitary"; the individuals taking no interest in one another except in connection with mating, but a number of species live in colonies and are described as gregarious, and this liking for one another's company may be normal and constant, or it may arise under certain conditions.

The mere crowding together of individuals is not necessarily a sign that the species is gregarious. For instance, flies will crowd together on a suitable food or on a suitable sunny wall; burying beetles assemble on a dead animal, and in such cases the crowding is merely the common attraction of the food or warmth. In many cases the crowding may be due to the sluggishness of individuals which emerge from a mass of eggs, and here we can only say that they find sufficient food on the

spot and do not object to one another's company.

For instance, many insects lay their eggs in masses on the food necessary for the young, and these young, after hatching, may stay together merely because they are slow movers and food is abundant on the spot, or they may actually appreciate one another's company. In the latter event they will probably continue together after the food supply on the spot has been eaten up.

There is, however, a type of gregariousness which affects certain insects occasionally, and it arises out of mere crowding. For instance, in different parts of the world our crops are attacked at intervals by vast numbers of caterpillars, which, although they are merely the product of large numbers of eggs laid in a limited area, have been thought by the farmers to develop miraculously and with great rapidity. An excessive number of hungry caterpillars in a crop naturally cause the rapid destruction of that crop, and it would be reasonable to expect that these caterpillars,

driven by hunger, would scatter in all directions in search of food. But this is not what happens; the caterpillars move off like a vast army all in one direction, and devastate a neighbouring crop, and then pass on again, and, not infrequently, one reads in the papers of a train having been stopped by hordes of caterpillars crossing the track. This sounds more marvellous than it really is, because the stopping of the train is not due to the immense wall of caterpillars, but to the slipping of the wheels on the crushed bodies.

That this sort of gregariousness and migration is casual is proved by the fact that such an army, although composed of 90 or 95 per cent. of one species, may include caterpillars of as many as ten species, these others being kinds which, under normal conditions, never swarm and never migrate in armies.

Again, everyone has seen or heard of swarms of locusts.

These insects are now known to have two phases or forms, one non-migrating or "solitary," and the other migratory and gregarious,

and it has recently been shown in the case of one species in Egypt that crowding the young tends to produce the migratory phase, while keeping them with plenty of room tends to produce the non-migratory (15).

But these gregarious insects are not necessarily social, and this raises the question, What is a social insect? A social insect is one in which the members of the family do something for the common good. This will possibly suggest to some people that some insects are endowed with Christian principles, and spend their lives in social-welfare work but, although the social life of insects is really very elaborate, it is, even in the highest forms, purely instinctive and without anything in the nature of what we call intelligence.

Insects which crowd together because they like one another's company may be doing something useful for the family in a rather peculiar way. Bright-coloured insects usually possess some quality which makes them undesirable as food for animals or birds. It may be that they are unpleasant to the taste, or, like

the wasp, have a means of protecting themselves, and we speak of such bright colouring, when associated with some protective character, as "warning coloration" (*see* Chapter II). Insects possessing warning coloration usually advertise their presence by sitting exposed in the sunlight instead of sheltering beneath the leaves, and so, if the members of a family possessing warning colours sit together, the advertisement is better. Therefore such insects would come within the definition of social insects. Thus gregariousness is the basis of social life, but the elaboration of that social life has depended upon some other qualities and, according to Professor Wheeler, one of these qualities has been the increased length of life of the mother insect. He contrasts human society with that of insects, and refers to the theory that human society has been made possible by the lengthening of infancy and childhood, and says that insects show us that the lengthening of the adult stage comes first, and makes social life possible, and that it is just the brevity of adult life that prevents the

development of the social habit in solitary forms, no matter how long the larval life may be (27). Although this view may be correct in accounting for the origin of social life in those insects, such as ants, bees, and wasps, which we all know as social insects, there is another type of social life developing at the present time in which the adult is not concerned at all, and we will discuss that and its origin after dealing with the life and habits of some of the well-known social insects.

In the first place, one would expect that the most elaborate social life would be found amongst those insects which we regard as the highest in the evolutionary line, but, although we find it in ants, bees, and wasps, which belong to one of the highest Orders of insects, we also find it in the Termites or so-called "white ants," which have nothing to do with the ants, and are one of the more primitive groups of insects. What we might describe as the elements of social life are found in other Orders, but there is nothing elaborate outside the two Orders already named.

The Termites, as comparatively recent investigation has shown, are probably descended from a common ancestor with the cockroaches, and, as Wheeler says, we are probably justified in regarding them as primitive social cockroaches, with an ancestry running back to the very earliest times. They are, and perhaps have always been, inhabitants of warm climates, where they rival the ants in their abundance, although, shunning the light as they do and being to a large extent subterranean, the visible evidence of their presence is mostly in the " nests " or " termitaria " of those which build on the ground or above it.

Within the group we can see all stages of social life, from the simple one in which only a few individuals are concerned, to the highly complex one where the individuals number hundreds of thousands. Where the individuals are few, the division of labour among members of the colony is but little marked, but in one of the complex colonies we find a number of different types or castes. In the first place, there is the so-called " queen," often the

only fertile female in the nest, an individual which, after the early days, of which I shall say something later, becomes a mere egg-laying machine, and produces vast numbers of eggs.

Secondly, there is the "king," the male which, with the queen, was the founder of the colony. His duties in the nest are apparently negligible: in fact, except as a mate for the queen, he does nothing. The bulk of the colony is made up of two groups of individuals: one known as "workers," with small heads, the other known as "soldiers," and these usually have large heads and often possess large jaws. The workers are of both sexes, but are normally sterile, although they are said to occasionally produce offspring, which, however, are always similar to themselves. No difference in the habits of the sexes has been noticed, and these practically sexless individuals do all the important work of the nest—building, storing food supplies, feeding the queen and king and the brood, of which they take entire charge. They are, in fact, the rulers of the society.

The soldiers are also of both sexes, and, like the workers, are said to be capable of reproducing their own kind under certain circumstances, though normally they are sterile and both sexes do the same work. But the description of them as soldiers is often a misnomer. They are, in many species, the first to run away in the event of a nest being broken open, and apparently do little that soldiers ought to do, although fanciful pictures have been drawn showing them forming a circle round the queen and guarding her in the royal cell. Nevertheless, even when they do not show fight they are a very important part of the colony, as they are the chief scavengers, and their scavenging consists in eating up everything which has to be removed. For instance, a sick or an injured individual is not carried away to hospital, but is eaten on the spot, from which we may assume that social insects are not troubled with sentiment, and are purely utilitarians.

Thus there are three castes in the termite nests, but this is really under-stating the case,

since as many as eight different castes have been described. The important point, however, is that there is only one fundamental adult type, and every other caste is this type, with slight special modifications, in some stage of immaturity. The immaturity affects not only the sexual organs, but also the external characters of the individual, so that the workers and soldiers are individuals which have not succeeded in attaining full development. This curtailment of development is apparently brought about by feeding in early stages, so that the proportions of the different castes in the nest are determined by the workers who bring up the brood. Either the quantity of food supplied or its nature determines whether the young are to develop fully and become winged males and females like their parents, or one of the arrested stages recognised as a caste.

Apparently the stage to which development is to go for workers and soldiers is determined in the very early days after hatching, since a peculiar caste occurs in some nests, apparently those in which the queen has died; individuals

which, although not fully developed externally, have matured their sexual organs sufficiently to be able to breed. The fecundity of these females, "substitution queens" as they are called, never reaches that of the real ones, and as many as fifteen "substitutes" may occur in nests where the real queen has died. It appears that these substitution royalties are produced from young individuals which have previously been destined to become workers, and, before the necessity for a new queen arose, have passed the susceptible stage at which they could have been made into royalties and thus, again, it seems that either quantity or quality of food can, even at a later stage, force on the development of the reproductive organs.

Some work has been done from which it seems possible that the story I have told of the workers and soldiers being merely individuals arrested in their development is not correct, since one observer has stated that there are two types of nymphs which hatch from the egg, and this suggests that one of these gives rise to one caste and the other to another, but

it is possible that further observations will correct this.

Each year those individuals which have been well nourished or specially fed become fully matured externally and internally, and develop large and useful wings. These individuals, males and females, escape from the nests, probably at the will of and by the orders of the commonwealth of workers, and fly out into space. The pairs, or those which survive the attacks of innumerable enemies, rub off their wings and dig a pit in the ground or burrow beneath a stone, and there they begin a new termitarium or nest. The young queen has all the trouble of bringing up her first brood, the young workers in their early stages being fed on the salivary fluid and excrement of the queen, and, when they become fully grown, these workers begin to develop the nest and to forage for food for themselves and the royal couple. Gradually the queen gives up work and devotes herself entirely to egg-laying, and to this end her body swells up to an enormous extent, so that in some species she is

as much as 20,000 times the volume of one of the worker caste, and it has been calculated that she lays as many as 30,000 eggs in a day, 10,000,000 in a year, and 100,000,000 during the ten years or so of her life. Now if the queen only lives about ten years, how is it that flourishing colonies exist whose nests are said to be much more than ten years old? Substitution queens would, of course, account for this, but substitution queens are not constantly found in nests, nor have they been found universally amongst termites, although there are termites which apparently rely entirely upon them and have no normal royalties. It may be, therefore, that young queens either return to their own homes or at least seek out existing nests to save themselves the trouble of starting a nursery for themselves.

With regard to the nest, although it always consists of innumerable galleries communicating at numerous places with one another, the material of which it is composed differs according to the species. Those species which nest in decaying wood or in the soil merely

excavate the galleries, whose walls may or may not be strengthened, presumably with excrement. Those species which construct nests which project above the ground, or from branches of trees, or from rocks and boulders, produce a material from earth or wood mixed with saliva, or swallowed and passed through the alimentary canal, which is at first plastic and can be moulded to form the walls of the passage, and then sets hard. In the case of the larger nests, built with earthy cement, and which may range from 10 to 20 feet in height, the hardness is such that the structure is sometimes even difficult to open with a pickaxe.

As soon as division of labour arises among social forms, it becomes necessary for some individuals to rely upon others for food supply, and this very early becomes associated with the habit of storing up food. We find amongst the termites that in many cases enlarged galleries or chambers in the nest contain masses of food material, which differs in its nature according to the species of termite.

In some cases large hay barns are found, grasses being cut up into short lengths and carried into the barns and stored there, but whereas such species merely reap where they have not sown, there are others which have developed an elaborate system of horticulture, since they cultivate fungi in gardens underneath the ground.

The work of these gardening termites is dealt with in Chapter VIII.

It was mentioned earlier that only in two Orders of insects had social life really become elaborate, and we will now discuss social forms in the second, that including the Ants, Bees, and Wasps, and here we have some points of special interest.

Although in the termites we find societies in a very primitive condition, consisting of but few individuals, and although we can say with some degree of certainty that the group arose from the cockroaches, we have but little evidence as to how the social life arose.

However, from the fact that the most primitive forms often have a number of kings and

queens in the nest, we might be justified in assuming that social life arose, as it apparently did in the bees and wasps, from associations of fertile individuals, through increasing sterility.

In the case of the bees and wasps, we are in a much better position, because, especially in the latter, we can see all the stages in the evolution of social life from solitary life, and, although we cannot find these stages among the ants, all trace of the origin of their social life having disappeared, we are justified in believing that their history was probably similar to that of the more modern bees and wasps.

Among the ants we find many things which remind us of the termites. For instance, the nest may be subterranean, or on the ground, or partly below and partly above; it may be in decaying wood or on living trees, and in the intricacies of its galleries it resembles the nest of the termites.

The subterranean galleries are merely excavations, which may or may not have their walls strengthened by the addition of small pellets of earth which have been chewed up

by the workers. Galleries above ground may be formed in material excavated from below, or in materials such as leaves, twigs, etc., gathered on the surface. Nests on trees may be composed of earth particles carried up and glued together with saliva, or of a vegetable material chewed into a kind of rough paper, but in all cases the galleries divide and join and form an intricate system, just as in the termite nest.

Among ants, we find a queen and her family forming a colony, but, whereas among termites one queen only is usually responsible for the vast population unless substitution queens have been produced, among ants it is not uncommon for a number of queens to live together in a nest, and their united families then form the population.

There are, however, certain remarkable differences between societies of termites and of ants, and one is that, whereas a termite colony usually only contains one size and type of worker, the ants have gone in for polymorphism, so that several types and sizes of worker

may occur, and this is associated with a greater division of labour amongst them, each size of worker having special duties in connection with the colony. Again, whereas the workers and soldiers of termites are composed of males and females, those of ants are composed entirely of females, which, like those of termites, are normally sterile, but can, under certain circumstances, lay eggs.

The origin of the ant colony may be similar to that of the termite—that is, by winged males and females swarming forth from their home, but whereas, in the case of the termites, the male and female remain together during their lives, in the case of the ants the male dies after mating, and leaves it to the female to carry out, by herself, the digging of the primary cell in which she will rear her first brood.

But ants have other ways of founding colonies, and one is by the partition of an already existing one, a party of workers, carrying brood and accompanied by a queen, setting off from the nest and starting a new one.

Such a method is really an extension rather than a partition, and frequently communication between the two parts continues indefinitely, and this same method of foundation of a new colony probably exists also among termites.

But a young queen on returning to the ground after her nuptial flight may be lucky: she may be seized by the workers of an existing nest and carried off to become one of several "egg-laying machines" in the nest, and in such a case she is, of course, saved all the trouble, and perhaps anxiety, of rearing her first brood. There are, however, species in which the young queens are apparently unwilling or unable to undergo the long fast involved in the early period of the colony, and these queens seek out existing nests and enter them. If the nests they enter are those of their own species, they are usually accepted without demur, but if, as often happens in some species, the nest entered is that of some other species, there may or may not be trouble. She may attack the workers, if they

are hostile, and even kill out the adults, including the queen, rearing the foreign brood, which later provides the nurses for her own family; or she may be accepted in the nest, and, after she has gained the confidence of the community, she will attack the rightful queen and, having killed her, will reign in her stead.

This method of founding a colony leads to a peculiar state of things, which, however, is only temporary. We start with a pure colony entered by a strange queen. This queen produces workers, so that, for a time, we have a mixed colony with workers of two species. As the original queen has been killed, her offspring sooner or later die out, and we finally have once more a pure colony, but of a different species.

Thus we see how ants, like human beings, will exploit one another for their own purposes, and regardless of the consequences to the exploited party.

The ancient history of this interesting Order is very difficult to unravel. It seems that, far back in the evolution of the group, the so-called

"Sphecoid wasps" separated off. These are represented to-day by many forms of "solitary wasps," which, however, are not closely related to other "solitary" species. In fact, we have two groups of wasps: the Sphecoids, from which have originated the Apoids or Bees, and the Vespoids, or True Wasps, which are the wasps with which we are all familiar, and which seem to show some connection with the stock from which the Ants evolved. Yet the bees and the true wasps have evolved along more or less parallel lines in their development of social life, and externally frequently show remarkable resemblances, so that the differences between bees and wasps are often by no means obvious. The most easily observed structural difference is the character of the hairs on the body, chiefly on the anterior parts. In the wasps, these are always simple and unbranched, whereas all bees have some or many branched hairs which resemble minute fir trees.

In habits, the two groups are easily distinguished, since the wasps feed their young on

insects, spiders, and such like, while the bees provide a diet of pollen and honey. Between social wasps and social bees there are some well-marked differences in habit, since the former construct their nests of chewed-up vegetable materials which make a kind of rough paper, and the cells which they construct are open below, so that the larvæ have to hold on in order to avoid falling out, while the bees construct their nests mostly of wax secreted from their own bodies, and the cells are never open below.

The outline of the life-history of a common wasp is as follows. In the spring young queens, which have slept all the winter in some sheltered position such as under loose bark or in holes in the ground, become active, and each one independently seeks out some place suitable for the commencement of a home. Some species select holes in the ground, while others select hollow trees or the branches of trees, and, having found a suitable situation, the queen constructs a small batch of paper cells, suspending them by means of a strong

paper cord from the support, a root underground or a branch of a tree, and surrounding them with a protective envelope. In each cell she lays an egg, fixing it in the upper (closed) end, and, when the larva hatches, the eggshell shrinks back, the larva remaining fixed in the apex of the cell.

The queen feeds these larvæ and adds to the length of each cell as the larva grows, and adds more cells to the original batch, this necessitating the reconstruction of the envelope which encloses them.

When the first small workers at last emerge, they assist their mother in the nursery and extend the nest, to which a second tier of cells is now added, suspended from the first tier by a number of paper ties.

More and more workers emerge, and more tiers are added to the nest, the envelope being frequently enlarged to contain them, until, by July or August, a successful nest may consist of about seven tiers of cells enclosed in an envelope, and, in the case of the Tree Wasp (*Vespa sylvestris*), may be more than 9 inches in

diameter, or in that of the Hornet (*Vespa crabro*) may be as much as 20 inches, but this latter species builds upon a broad base, instead of suspending the nest.

Towards the end of the season and in the lower tiers of cells, the future queens and the drones are reared, and, when the cold is chilling the blood of the community, these young queens, having mated, depart in search of winter quarters, while the workers pull out and destroy the remaining brood, and they and the old queen disperse and go to sleep and never wake again. Thus the life of the colony lasts only for the season, though in the tropics there are perennial colonies of wasps which apparently send out flying swarms, as do the ants. As in the case of the ants, the worker wasps, under certain circumstances, lay eggs, and these produce drones.

The life-history of the humble-bee is very similar to that of the wasp, the colony being started in the spring by a queen which has survived the winter in a torpid condition, the young queens and drones being produced at

the end of the season after the workers have completed the waxen nest and laid up a store of honey in many of the old brood cells to tide over the wet and cold days when little or no foraging can be done. The fate of the colony is similar to that of the wasp colony.

The hive- or honey-bee has improved on this type of life-history, and this improvement is partly based upon the longevity of the queen, who may live a number of years and remain fertile all the time.

The workers, during the flower season, are short-lived, but those hatched late in the season survive the winter in the sealed-up nest. The waxen cells of the hive bee are horizontal, not vertical, excepting the royal cells, which are specially constructed.

Although the queen lives three or more years, her death does not end the existence of the colony—in fact, the old queen may be sent off with a swarm long before she has reached her limit, and a young queen, one of her daughters, may reign in her stead.

In this perennial type of colony we see the

young queens taking their nuptial flight and returning to their old home, so that the same thing may well occur occasionally among the termites, although there is this noticeable difference in the two types : none of the members of a termite family normally leaves home alone and wanders far and wide, as do the members of the hive-bee family, in which there is a definite sense of locality.

The mother queen of the hive-bee always has murderous intentions towards her own royal daughters, and they, in turn, always destroy one another if the workers permit them to meet, so that the management of the blue-blooded individuals must be a little difficult for the workers.

Young queens are apparently only produced either when the old queen is getting past her work or when the workers decide that a swarm should be sent out. The swarm consists of a queen, some drones, and a number of workers, and this excited mob of bees either flies direct to some place, apparently prearranged by the workers, or makes a temporary

halt in a tree or on a wall, the whole swarm forming a thick cluster around the queen.

As in the termites and wasps, the worker bees are normally sterile, but occasionally lay eggs which produce males. It has been clearly demonstrated that the egg which is destined to produce a female gives rise to a larva or grub, which becomes either a fertile queen or a worker, and that the result depends upon the food provided by the workers. The larva which is to produce a queen is constantly attended by "nurses," which feed her upon what is called "royal jelly," a material containing more proteid and fat and less glucose than that upon which the worker is fed, and this rich food causes the reproductive organs of the individual to become fully developed, and the whole development of the grub is completed more rapidly than that of the worker, the former becoming full grown in about sixteen days, whereas the worker grub requires three weeks before she is ready to become a pupa.

It has been assumed, upon the facts known

with regard to the honey-bee, that all these social insects which have been referred to produce queens or workers, according to the nature of the food, and, after the very careful investigation of their habits which has been made by many observers (and with the possible exception referred to in connection with the termites, where, it will be remembered, one observer had recorded differences in nymphs emerging from the eggs) it seems clear that there is nothing else which could account for the facts.

In the termites, as has already been said, the sterile members of the community consist of both sexes, whereas in the higher Order only females occur among the workers, and it is interesting, therefore, to inquire what it is that determines the sex in the social insects and enables the colony to keep up the supply of useful females and to keep down that of the almost useless males.

The question of sex determination has apparently not been investigated in the termites, but it has been very thoroughly gone

into in the case of the ants, bees, and wasps, and, although there are still some details which are disputed, the main facts are quite clear.

In the large majority of insects, the female, after receiving the spermatozoa from the male at mating, stores them up in a special receptacle, where they remain alive until they are required to fertilise the eggs, a considerable period often elasping before this time arrives. As the eggs are laid, the spermatozoa pass to them, but in many cases the female can withhold the spermatozoa and lay unfertilised eggs.

In the case of the queen bee, it was suggested many years ago by Dzierzon that fertilised eggs produced females, while unfertilised eggs produced males. Dzierzon's hypothesis was accepted as being true of hive-bees, and was also regarded as true of humble-bees, solitary bees, and social and solitary wasps, and also of ants, but, within the last thirty years, a number of observers have discovered apparent exceptions. It has long been

regarded as true that worker ants, bees, and wasps are incapable of mating, and that, on the occasions when these sterile females lay eggs, their offspring, being from unfertilised eggs, are always male. Yet at least five observers have recorded cases among ants where a nest, deprived of the queen, has continued to produce workers, and in 1912 the Cape honey-bee, which is a race of the Common Honey-bee (*Apis mellifica*), was recorded as producing workers in the absence of a queen. Although at the time the accuracy of this observation was disputed, the discoveries in connection with ants make it not improbable; in fact Wheeler says, " There is every reason to suppose that the workers produce not only males, but workers and even queens " (27).

More recently one observer has stated that by placing worker larvæ in drone cells, the workers produced, from these female grubs, a number of male bees, and a repetition of the experiment by another observer gave the same result (9, p. 197).

The retarding of the development of an

individual and of its reproductive organs by means of special feeding does not now seem miraculous, especially considering all that has been discovered concerning the effects of certain substances, such as thyroid gland, in feeding experiments on tadpoles, etc., but changing the sex is something very different, especially as we now know that Dzierzon's hypothesis is correct, since microscopic examination of the eggs laid by the queen bee in worker cells and queen cells shows that they contain spermatozoa, whereas those eggs laid in the drone cells do not—a fact which seems to indicate definitely that the unfertilised egg is male, and that the spermatozoa is the essential addition for the production of the female.

The explanation apparently lies in the fact that the arrival of the spermatozoon brings to the egg something—perhaps an enzyme—which can be supplied in another way—that is, by special food to the newly hatched larva or grub. Goldschmidt has pointed out that sex mechanism of the bee's egg differs from that found

almost everywhere else in the Animal Kingdom, and it seems probable that the unfertilised egg is bi-sexual, and that, under normal conditions, the production of male-producing enzyme is more rapid than that of female-producing enzyme, in consequence of which males result. The presence of the spermatozoon, however, either hastens the development of the female-producing enzyme or checks that of the male-producing enzyme, and thus the female sex results.

If the observations and experiments above referred to are correct, they indicate that the struggle between the two sexes continues after the hatching of the egg, and that the workers can re-establish the dominance of either by some special treatment of the larva, presumably by the supply of a special food containing the necessary enzyme.

In this chapter we have outlined the types of social life existing in those insects in which this phenomenon has developed farthest, and we can recognise that, in addition to the increased longevity of the mother already referred to,

there are certain definite processes associated with its evolution : increased fecundity of the mother, associated with sterility more or less complete of the worker and the power of the community to determine the sex of the offspring and its fertility or sterility—if a female; the inevitable destiny of each individual to perform the duties allotted to it; and the complete destruction of individuality. In the next chapter we will begin by considering how this has been brought about.

CHAPTER VIII

SOCIAL LIFE AND THE INDUSTRIES OF SOCIAL INSECTS

WE have already seen that the wasps and bees originated from a common stock and have evolved along more or less parallel lines, each group having produced social forms, and yet still including a majority of solitary ones.

In order to trace how this social life has evolved we will only discuss the wasps, as the story is more complete in their case, and there is no reason to doubt that the bees have followed along much the same lines.

Just as we can recognise by structural characters more primitive and more advanced forms, and can trace out the probable course of evolution of the latter, so we can trace the probable evolution of habits within a group by assuming that the forms with simpler

habits indicate stages passed through by the forms with more elaborate ones.

On this basis it is possible to trace the probable evolution of social habits, and we will use the wasps for this purpose, as there are more links in the chain than in the bees.

The solitary "Vespoids," or true wasps, resemble in their habits the "Sphecoids," from which probably the bees originated. In the solitary forms there are no worker caste, each female doing her own work of providing for her progeny.

Each species provides some special type of food for its offspring, and in the majority of cases this food, which is either an insect, in its adult or young condition, or a spider, is paralysed by stinging, so that the larva of the wasp feeds upon living prey.

In the simplest type, such as the Scolia, the mother wasp burrows in the ground or in decaying vegetable material or rotten wood in search of the larvæ of chafer beetles. Having found one, she curves her abdomen so as to bring its apex beneath the beetle larva and

drives her sting into it, until, having entered the nerve ganglia, the prey loses the power of co-ordinated movement. The Scolia then lays her egg upon its side in such a position that it is safe from moving jaws or legs, and the wasp grub, on hatching, feeds upon the fat beetle larva, without moving from the spot where it hatches.

Thus the wasp in this case neither provides nor stores a cell for its offspring, but lays its eggs wherever the prey may happen to be. But in such a form as Calicurgus, one of the Pompilid Family, the mother provides spiders for her future offspring, and, having found and paralysed one, she carries it until she finds a suitable hole, such as a deserted worm burrow, in which she stores it. After laying her egg upon it, she stops the entrance to the burrow with pellets of earth moistened from her mouth and chewed up by her jaws. Certain related Pompilids go further, and, instead of seeking a ready-made burrow, they dig one out for themselves.

So far the habits are simple, and the wasps

first secure the prey and then proceed to dispose of it, but the next advance is where the " nest " is first prepared before the search for the prey commences. Here we see a new factor coming in, since the insect has to remember the position of the burrow in order to return to it, and this involves learning the geography of the locality.

Such an insect frequently goes far afield in search of the prey, and Fabre found, in the case of a Cerceris, one of the " Sphecoid " wasps, that this wasp could find its way home again even when carried one and a half miles away from it (7).

In some of these cases the egg is laid on the prey after it has been brought into the cell, and in others the egg is laid in the cell before the prey is captured, and presumably the latter is the more recent accomplishment.

Many of these wasps are entirely solitary in their habits, while others are gregarious, large numbers resorting to some common ground—a bank, a gravel pit, or a rotting tree—and constructing their galleries in close proximity.

But even in these cases each female carries on her own work, although mistakes are not infrequently made which involve the pulling out by the rightful owner of an unfortunate individual who has entered the wrong gallery. The species of the genera Odynerus and Synagris include excellent examples of these gregarious forms.

Very rarely in such species two individuals may co-operate in some piece of work, such as closing a gallery, but it is most probable that, in such a case, the two individuals both believe they are working at their own gallery, and disregard rather than appreciate the presence of the other.

On the other hand, there are wasps which are not only gregarious, but do work together, and so come within our definition of a social insect (*vide*, p. 157); for instance, a certain African species of the genus Belenogaster. A female of this species starts building her paper cells, and may be joined by other females, which add their cells to hers, but they are less particular about keeping to their own work,

and may be frequently seen working together harmoniously at a single cell. There is even a slight division of labour amongst them, since the recently emerged individuals, possibly not being quite ready to lay eggs, assume the rôle of foragers, and only later give this up in order to devote themselves to their own egg-laying.

In this particular African species all the females are apparently equally fertile, but in certain related South American species some of the emerging females are sterile, so that the colony, which may include hundreds and even thousands of individuals, consists of a mixture of fertile and sterile females.

The change from such a type to a social insect such as the common wasp only requires increasing sterility in the colony and increasing fecundity of the fertile females, and increased fecundity is almost necessarily associated with increased length of life.

We may perhaps surmise that the termite society arose in the same way, but it is not necessarily the only way, because, as mentioned in the previous chapter, there is a type

of social life to be found amongst caterpillars which has nothing to do with the longevity of the parent: in fact, the parent is not in any way concerned in it (1).

If Wheeler was correct in ascribing the first importance to parental longevity in the case of those forms already discussed, then we may say that the point of first importance in this other type of social life is the fact that these forms produce silk. In most caterpillars the salivary glands are greatly enlarged and perpetually ooze saliva from the tip of the tongue or "spinneret," and this fluid issues forth as a sticky thread. When the caterpillar feeds, no doubt the saliva mixes with the material bitten off by the powerful jaws, and aids digestion, but when the caterpillar walks, it leaves a trail behind it in the form of a fine silken thread.

This thread is useful in several ways. In the first place, it enables the caterpillar to retrace its steps, and it is of great importance to those kinds which feed upon the foliage of trees. Should they be shaken from their

feeding-place by a gust of wind or by a bird or other disturber, a fall to the ground might mean a long and uncertain walk, since caterpillars are usually rather particular about their food, and mixed forest is more natural than pure growths of one kind of tree. The unfortunate creature might have to walk up several trees before it again found its right food plant.

The silken thread is a guide-line, up which it can return to its original perch. By means of a wonderful apparatus inside the base of the spinneret, the caterpillar can check the outflow of the thread, so that it does not necessarily fall the whole way to the ground, and then, by means of jaws and winding the silk round its legs, it can climb up the swinging thread.

To avoid such accidents or to lessen the likelihood of their occurrence, many caterpillars take the precaution of spinning a small silken mat on the leaf where they are feeding, and this gives them firm foothold on the otherwise slippery; leaf and again, many

caterpillars which do not do this regularly, spin the mat at the times when they are going to moult—that is, cast their skin.

Everyone also knows the use of the silk by many full-grown caterpillars for spinning a cocoon within which they change into pupæ, from which the adult moths or butterflies ultimately escape. Now many butterflies and moths lay their eggs in masses, and often, although not always, the young caterpillars, when they hatch, remain together and feed together. If, in such a case, each of these caterpillars spins a mat for its own safety, the mats will overlap and a large "carpet web" will result, and these caterpillars at once come within our definition of social insects—the members of the family doing something for the common good. The common "Large White" or "Cabbage" Butterfly (*Pieris brassicæ*) is an excellent example—the caterpillars spreading a thin white carpet over the leaves and crowding together upon this. In this species the social life continues until the caterpillars are full grown, when they disperse in order to

pupate, but there are other species in which social life endures for only the early part of the caterpillar life. For instance, the Buff-tip Moth Caterpillars (*Pygæra bucephala*) are social during the first stage or two of their life, but after that they give up spinning a carpet, so that, although the gregarious instinct remains in the older stages, the family breaking up into small parties, they cannot be regarded as social.

The carpet web serves the function of providing a foothold, but leaves the caterpillars exposed to attack. We might therefore regard as an advance on the carpet web a structure within which the caterpillars dwell and feed, and there are many examples of this. For instance, the caterpillars of the common "Small Tortoise-shell" Butterfly (*Vanessa urticæ*) or of the "Peacock" (*Vanessa io*), as soon as they hatch from the egg, commence to spin a fine web around the nettle-heads or cluster of nettle-flowers amongst which the mother butterfly deposited the batch of eggs. Within this they feed, but, as can readily

be understood, the food soon becomes exhausted. The family then extends the web so as to include more leaves, and so the white film spreads up or down the nettle-stalk. Such a web may be described as a "feeding web." The caterpillars never leave it so long as they continue to make it, but, by the time they have reached the second or third stage, they give up this method of working, and the family breaks up into small parties, which collect on the undersides of larger nettle-leaves and draw in the edges, so as to make the leaf into a more or less closed shelter. They then proceed to eat the leaf, and, having destroyed their house, they move elsewhere.

After one or two such shelters have been constructed, the caterpillars, although remaining gregarious, cease to be social, and when full grown they disperse, and, suspending themselves head downwards, each one becomes a pupa or chrysalis.

We might regard the second stage of these caterpillars as an advance on the first—that is, the fixed shelter as an advance upon the

shelter which is continually being extended as the food beneath it is consumed—although it is difficult to regard the change of habit as showing more sense, since the shelter is eaten up as soon as made.

There are, however, caterpillars which seem to acquire more sense as they grow. For instance, those of the Lackey Moth (*Clisiocampa neustria*) construct a feeding web immediately after hatching, but, at the end of about eight days, having destroyed this, they move off, and in so doing usually break the family into two or more parties, and each party constructs a firm nest which is meant to endure, as the caterpillars are constantly adding silk to the outside. Once the food within has been consumed there are two alternatives for the occupants: either they must desert the web and move elsewhere, or they can go out to feed and return home when satisfied. The Lackeys have adopted the latter method, the " home-web " serving them until they are more than half grown. By that time they seem to be much less gregariously

inclined, or else, through carelessness, they have mostly walked off the end of branches of the tree, and, since they do not produce a silken thread strong enough to carry them, the chances of their finding their way back are very poor. If, however, a number do continue together until the last stage of their caterpillar existence, they desert the home web, which is usually near the top of the tree, and descend to the lower branches, where, on the trunk or in a fork, they construct a "carpet web," which they finally desert, when each caterpillar seeks a secluded spot amongst the leaves and spins a white silken cocoon and changes to a pupa.

The last stage in the evolution of the web is that in which the caterpillars commence a home web when they hatch and continue to add to it, never destroying the rafters upon which it is constructed, and returning to it in the intervals between feeding, so long as they remain social. The little Eggar Moth (*Eriogaster lanestris*) is a good example of this type.

The home web, as we have seen, necessitates going out to feed, and, where a family consists of a hundred or more caterpillars, the food in the immediate neighbourhood soon becomes exhausted, and this means longer and longer journeys to the feeding-grounds. As, however, each caterpillar lays down a silken thread as it walks, there soon appear broad white tracks leading outwards in all directions from the nest, and the caterpillars have no difficulty in retracing their steps after feeding.

Although the few examples I have mentioned, in tracing the evolution of social life, are all British, there are large numbers of species in all parts of the world which show the same stages, and whereas, in some cases, as we have seen, the family disperses early or late, in others the caterpillars remain together to the last and even pupate together in the larval web.

In the case of the Small Ermine Moth (*Hyponomeuta* or *Yponomeuta*), which makes a "feeding web," not only do parties of caterpillars form their cocoons in pockets in the

larval web, but the moths, on hatching out, are so sluggish that many of them lay their eggs in close proximity: thus many families may emerge and join their feeding-webs, which may then extend over a considerable area of hedge.

We have now traced the evolution of a type of social life which is clearly very different from that described in the previous chapter, one in which the adult has been in no way concerned, and it is interesting to note that a similar type of social life is evolving amongst the caterpillar-like larvæ of the Sawflies, a group of insects related to the Bees and Wasps.

If the adult should ever become involved in this social life, and begin to take an interest in her offspring, it seems reasonable to believe that it might become quite like that already described in the last chapter, so that, without a knowledge of previous history, we might regard the origin of all as having been identical. That the adult may become involved is evidenced by an observation of Froggatt in

Australia in 1901, where a female Sawfly (*Perga lewisi*) "not only stands guard over them (her eggs) until they are hatched, but, further, looks after the helpless grubs for some time after they have commenced feeding. She straddles the eggs with her wings half opened, the tip of her abdomen turned up, and with her jaws open, makes a slight buzzing sound if meddled with; if you pick her up, she never attempts to fly, but crawls back to her post, reminding one of an old hen protecting her chicks" (8).

Here we see increased longevity—which, as will be remembered, was, according to Wheeler, one of the important factors in the production of social life.

So far we have described very briefly the main points in the social life of those types in which it has become something very definite, but the social insects have not been content with elementary communal existence, they have evolved what we may describe as industries, and, as we should expect, these are only developed in the two groups in which

social life is of very long standing, the termites and the ants.

These industries are based upon the necessity for food storage, and the most interesting one amongst the termites is horticulture. The bringing in of food to supply the growing young is obviously a necessary commencement in the community, and growing the necessary material is an important advance. A number of different termites have developed the art of growing fungi as food for the young. The fungus garden is constructed in subterranean chambers, and the soil of the garden consists of decaying wood and perhaps other vegetable material, which has been eaten by the workers and has passed through their bodies. The fungi, of which more than one species have been recognised, apparently normally live in decaying wood, and the spores of these fungi pass uninjured through the alimentary canals of the workers.

It seems as if the fungus-garden idea had arisen through these termite communities

having made certain sanitary-rules by which the individuals were instructed to void their excrement only in certain places, and this seems further to be borne out by the fact that there is no material supplied for the growth of the fungi, other than the excrement—a very different state of affairs from what exists in the ants which cultivate fungus gardens. In some cases, special ventilating shafts are run up from these "public lavatories." The fungus extends its fine threads throughout the soil and throws up aerial growths, which form the food of the young termites in their early stages, and continue to form the food of those individuals which are destined to become kings and queens. The king and queen in the nest are also supplied by the workers with this fungus food. The workers and soldiers are quickly weaned from it, and take to the rotting-wood diet, which, however, contains the hyphæ and spores of the uncultivated fungus. Possibly, therefore, the cultivated fungus contains some enzyme which affects the

reproductive organs of the individuals which are permanently fed upon it.

Excepting for this important industry, there is nothing else comparable to those of ants, except something which in the termites cannot be described as an industry. Amongst termites more than one species may live in a nest, and, at any rate in some such cases, one of the species lacks one or more of the castes. This suggests either that the one species is more or less dependent upon the other, or, alternatively, that they mutually aid one another. We shall revert to this when we consider slave-making as an industry among the ants, but, in turning to this group, we will commence by comparing the horticultural activities with those of the termites. The ants which undertake this work are known as "Leaf-cutter" or "Parasol" Ants, and, whereas all the horticultural termites are confined to the Old World, all the horticultural ants are confined to Central and South America and the West Indies. The leaf-cutting habit is purely for the purpose of

providing material suitable for the cultivation of the fungi, and not, as was at one time suggested, in order to provide parasols for the workers.

In the colonies, which are composed of large numbers of individuals, from 175,000 to 600,000, there are several sizes of workers, and the smallest of these—a very small one compared with the largest—is responsible for somehow treating the fungus so as to cause it to produce the special small globular bodies which form the food of the whole colony. As in the case of the termites, the fungi cultivated by the ants occur independently of the insects, but never develop the food bodies except under conditions provided by the ants. One of these fungi, under natural conditions, produces a large mushroom above the ground, which may be 16 inches or more across the umbrella, but a number of different fungi are cultivated by the different species of ants.

The founding of the colony of one of these leaf-cutters makes an interesting story. As usual, at the appointed time the workers

send out the winged individuals from the nest, but the females of these, before leaving home, make an attack upon the fungus garden and pack some of the soil containing the fungus threads or hyphæ into a pouch inside the mouth, a pouch possessed by ants, bees, and wasps, and which, among other things, is often used for carrying minute drops of water to the nest.

A female, having left the nest and mated, returns to the ground, and, after rubbing off her now unnecessary wings, digs her way into the soil. Having made a cell, she disgorges the pellet from the pouch and spreads it out on the floor, and, amongst it, she lays a batch of eggs which hatch in about a fortnight. It has been said that these early larvæ are fed upon eggs, which the queen, having laid, seizes with her jaws and pushes against the mouths of the grubs, and that one egg is sufficient for several young larvæ. On the other hand, it has been stated that these early larvæ at once proceed to feed upon the growing hyphæ of the fungus. The queen

constantly attends to the fungus, licking the hyphæ and manuring the material with her excreta, and breaking up eggs and supplying them to the mycelium, and apparently feeding herself upon her own eggs, which reminds one of the village where the people supported themselves by taking in one another's washing.

As soon as these first grubs become workers, a new era begins for the small colony. They share the work of cultivating and spreading the garden, and assist in feeding younger larvæ, but they are very small and do nothing in the way of nest-building. The next batch of workers to emerge, perhaps owing to better feeding and attention, are larger and have larger heads, and they at once open up communication with the outside world and start to expand the nest, and now begins the leaf-cutting. The cell containing the garden having been greatly enlarged, columns of these larger workers proceed to the surface, and climb a tree or shrub, where each individual proceeds to cut a large piece

out of a leaf. The column then returns home, the pieces of leaf, sometimes much larger than the carrier, being borne along, sometimes vertically and sometimes horizontally, and often completely concealing the ant. As the tree selected is sometimes a considerable distance from the nest, these columns are frequently many yards long, and appear to be animated pieces of leaf moving in procession. This vegetation is carried down into the underground garden, which is being continually extended into other subterranean cavities, and, after being vigorously chewed, is scattered round the edges of the growing fungus, which rapidly spreads on to the now fermenting vegetation. The constant pruning or other treatment to which the hyphæ are subjected causes them to produce the food bodies upon which the whole family now relies for its food supply.

The nests of some of these ants sometimes extend more than 5 feet beneath the surface, and spread outwards in all directions.

There is another kind of gardening ant, but

the object of the gardening in this case is not to cultivate food. These ants, of which there are several kinds all occurring in the forests of Brazil, build their globular nests of earth, carried up to the branches of the trees.

In these tropical forests, with their heavy rainfall, such a nest would run great risk of being washed away, but it quickly becomes the centre of a growing mass of young plants, the seeds of which have been carried up by the ants, either unconsciously in the particles of soil or, according to one authority, deliberately. The roots of these seedlings quickly spread in the ball of earth, and so bind it together, and the galleries of the nest run amongst the tangle of roots.

The harvesting ants gather in seeds and store them in barns deep beneath the ground. This sounds very much like the process which we recognise as planting, and one would expect these stored seeds to sprout, which would make them useless to the ants. But the harvesters seem to know all about the habits of seeds, and, on the top of the nest, before

taking them down, they bite out the embryo, leaving only the food material upon which the young plant would have fed in its early days until it had produced its root and first leaves. Consequently the surface of the nest becomes covered with chaff and refuse, and, as the ants seem to be rather careless about the process, many seeds are taken down without having been treated, and these seeds germinate in the usual manner, and the plants grow up through the roof. As these ants specialise in certain somewhat rare grass seeds, their nests are frequently recognisable, apart from the chaff, by the tufts of this grass growing upon them. It is a well-known fact that large numbers of insects are to be found on trees and bushes whose leaves are covered with a sticky material known as "honey-dew." This sticky substance is nothing but the excretion of millions of aphides or "green fly," or of scale insects which are sucking the sap of the trees, and their digestion is such that the fluid which they excrete is largely sugar and water. Most ants are very fond of this fluid, and they may be

seen walking over the crowded masses of aphides and stroking them with their feelers or antennæ. Now the aphide under normal conditions casts its excretory fluid from it, but, under the influence of the ant, it allows the fluid to pass out slowly, and the ant licks it up.

The majority of ants go out in search of the "cows," and may even construct papery shelters over them on the plants, but in some cases the ants keep the aphides in their nests. These aphides are root-suckers, and the ants expose roots in the walls of the chambers within the nest and place the "cows" upon them to feed. Some of the aphides are said to be only found in association with ants.

Various other insects, such as scale insects, mealy bugs and other small bugs, and even caterpillars, are of interest to the ants, either by reason of their excretory fluids or, as in the case of the caterpillars, by reason of a secretion from certain special glands. The caterpillars, and even pupæ of some of the "blues" among the butterflies, are definitely myrmecophilous.

This relationship between ants and these insects is obviously of mutual benefit, since the ants, in return for liquid food, give protection and shelter.

In some parts of the world where there is a very dry season, and where for a long period there is no water and the vegetation is dried up, several kinds of ants, not closely related to one another, have taken to the business of honey-storing to provide food and drink during the season when it is otherwise unobtainable. But whereas bees and some wasps store honey in cells which they make for the purpose, these ants have not acquired the art of pottery-making, and they make some of their own worker caste into living honey tubs.

There are several stages in this industry, and in the less advanced species the workers in the nest receive in their mouths the honey manufactured from the nectar of flowers in the crops of the foragers, and then dispense it to other individuals. Their bodies are capable of swelling up to a limited extent, but these honey purveyors can always walk about. In the true honey ants, however, the indi-

viduals which receive the honey from the foragers are capable of such expansion that their abdomens become spherical, and make the owners quite incapable of walking. When they are quite full, these honey tubs are carried by the other workers and stored up in subterranean chambers, each one being lifted up until, with its jaws, it gets hold of some rootlet in the roof, and there hangs until it is again taken down to disgorge some of its contents.

Perhaps it sounds strange to refer to slave-making among ants as an industry, but its supposed origin seems to justify this. Darwin suggested that slave-making arose in consequence of certain species of ants adopting the habit of raiding the nests of other species in search of brood to be used as food, and that, as more food than was necessary for immediate requirements was often brought home, it was stored for later use. Some of this brood hatched out in the store-rooms, and, acquiring the smell of the nest, the resulting workers were not interfered with, and, having nothing better to do, joined in the work of the nest.

If this explanation is correct, slave-making, as such, had an innocent beginning, but, as we shall see, it has been carried too far, and has caused degeneration among the slave-makers.

As an example of slave-making in its simplest and most harmless form, we will detail the habits of the ant known as *Formica sanguinea.* It is difficult to find a suitable English name for this species, as offence might be taken at a literal translation of the Latin and a great deal attaches to a proper use of words. For instance, no one could object to a reference to his ruddy complexion, whereas a man might with justice complain of a remark concerning his bloody cheek.

This species nests under stones or in logs of wood, and its habits vary with the locality, since, in some localities, most nests contain no slaves, whereas in others most of the nests contain them. Thus the species can be independent, and, even where the slaves occur, the sanguineas treat them as equals in the ordinary affairs of the colony, and only exclude them from participating in the raids.

The raids only occur in July and August, apparently after the nests to be invaded have sent out their winged males and females, so that these nests are then occupied only by the queen or queens, the workers, and the brood.

The raiders suddenly issue forth from their home and make a bee-line for the objective, and, as there is no definite leader, it seems clear that the whole army knows the way. It is probable, therefore, that the raids are planned beforehand, the sanguinea workers presumably learning the situations of suitable nests during the spring and early summer, while foraging. The whole affair is frequently quite bloodless, since, unless the occupants of the raided nest show fight, the sanguinea do not interfere with them. Only the brood is wanted, and any attempt on the part of the owners to carry it to a place of safety is thwarted at once. Each sanguinea, having seized a larvæ or pupa, returns home as rapidly as possible, and the brood is then taken charge of by the nurses, who may be sanguinea or slaves, and is hatched out.

We may speak of such slavery as a luxury, but in some species it has become a necessity, because these species have become dependent upon their slaves. The Amazon Ants (*Polyergus*), for instance, cannot make their own nest nor bring up their young; in fact, they can scarcely feed themselves. The sole function of the workers is to raid; they are soldiers, and the nest of the Amazon contains more slaves than masters. The nest is managed by the slaves, who take over the captives when the raiders return and even go out to bring in raiders who have lost their way.

This degeneration of the Amazon has made impossible the ordinary method of starting a new colony, as the queen is quite incapable of digging a cell for herself or of rearing her first batch of young. Therefore the Amazon queens are dependent upon their success in entering another nest, where they ultimately kill the queen and have the existing workers to look after the brood.

Whether we can regard the next as an

example of degeneration due to the practice of slave-making is perhaps questionable, but such a type as *Anergates* produces no workers, and is therefore entirely dependent upon foreigners for her subsistence.

The young queen enters a foreign nest and, sooner or later, kills the foreign queen. The foreign workers then rear her brood, but, as her eggs only produce males and fertile females, the community comes to an end with the death of the foreign workers, which takes place after they have reared the *Anergates* young. This is really a case of parasitism, and it is associated with degeneracy on the part of the female, both in form and in habit, as she cannot even feed herself, and the males are even more degenerate, of sluggish habit, and more or less pupa-like in appearance.

This short sketch of the habits of social insects gives a very imperfect idea of the wonders of instinct, because it must be remembered that all the most complex acts which occur are unintelligent and mere responses to definite stimuli. We are usually

in the habit of regarding instinctive acts as something inferior to what we call intelligent ones, but another view has been put forward. When we have, by the use of intelligence, learnt to perform some particular act—such as putting up an arm as a defence against a threatened blow—such an act after a time becomes " instinctive," and we do it without thinking, when the stimulus occurs. Again we learn painfully to ride a bicycle or to knit, and, after a time, we can do either of these things without thinking about them. They have become " instinctive."

It is possible, therefore, to regard the wonderful acts of social insects as having originated as intelligent responses, and as having, through scores of generations, become instinctive.

In the solitary insects we may regard the male as the dominant sex, since he possesses the special adornments, when the species has any, and is the less passive. In the social insects, on the other hand, with the exception of the more primitive termites and of the

caterpillars which are sexually immature, the female dominates, the male having degenerated.

If we compare the evolution of social life in insects with that in human beings, we see certain vague similarities. With nomad man the female was a mere chattel, and not so long ago, even in the most civilised countries, woman was still the inferior sex and regarded as a chattel by the law. Recently she has asserted her rights to equality, and she is competing with man for wage-earning positions, and thus seriously affecting the home relationship. Coincident and, partly, at least, associated with this changed position of the sexes comes an increasing interest in birth control; and these things are all movements in the direction of those taken by insects.

We may perhaps go no farther than the termites in the deterioration of the male—and it is deterioration of the male which accompanies the changed outlook of the female—but, if it is a law of Nature that all

social groups must evolve on the same lines, the future of the human being is not too promising, from our present-day point of view. The children, of those who are allowed to have any, will be dedicated from birth to fill some gap in the economic machine, and human society will do everything to exterminate individuality and to reduce all the workers to a common level.

CHAPTER IX

HINTS ON COLLECTING INSECTS

To the average man or woman, insect-collecting means running about with a butterfly net, and a pleasant way of wasting time, but collecting is really a fine art and calls for any amount of ingenuity. There are good collectors and bad collectors—that is, there are people who can find things and there are others who cannot. Even among the former there are remarkable differences, and two experienced collectors on the same spot will usually each find things which the other fails to find.

But although a good collector is probably born with the gift, experience is invaluable, so that, as in so many other things, one can improve with practice.

Now collecting may be merely finding insects and arranging them in a collection, or it may mean something more, and here lies the differ-

ence between the mere collector and the naturalist. The former enjoys his days in the country and takes pleasure in arranging his captures, but he is not interested in the specimens except as "objects of art."

The latter is getting the same pleasures as the former, but he is interested in the living things, their structure or their habits, and the collection is made as a means towards an end, because it is necessary to know something about the classification of the group. Thus there is a great difference between the ornamental collection and the working collection.

The former contains a few specimens of each species, beautifully mounted and regularly arranged, with labels exactly horizontal and everything neat, while the latter contains perhaps dozens of specimens of many species, mounted irregularly, indifferently set, and labelled with any slip of paper which came handy at the time. The ornamental collection merely contains a few specimens to represent a species; the working collection contains many specimens to represent the species from

various districts, some specimens partly dissected, others reversed, and so on.

What has been said would seem to indicate that the ornamental collection is useless, and that the owner of it has merely wasted his time, but that is not what is intended. The mere collector is getting together material which may, quite probably, be turned to good use by some one else, and many an old collection has provided useful data for those studying the problems of distribution—if the specimens have been labelled with date and locality. Therefore, to those who have no time for anything more than mere collecting we would say, "Go on with it: enjoy the exercise and the finding of the specimens, and, later, enjoy the memories of the happy days which the insects will bring back to you, but label your specimens with full particulars, and so make your contribution to science."

As a rule, a collector specialises on one Order of insects, or even upon a small group within the Order, but a beginner would do well to be, for a time, a more or less general collector,

as, by handling insects of the different Orders, he will learn much more about them than by studying textbooks or examining other people's collections.

Each specialist acquires a collection of apparatus to suit his methods of collecting, but there are certain instruments which are of general use, and amongst these are the so-called butterfly net, the sweeping net, and the beating tray. The first of these is so well known that it is scarcely necessary to say anything about it. Each collector prefers and adopts some particular pattern, size, weight, and colour, but there are advantages in light weight and large-sized cane "rings" over heavier and smaller ones for general purposes, and a bag with a blunt apex is of more general use than one which is square or evenly rounded.

For sweeping flower-heads and similar light work, the butterfly net is quite efficient, but, for heavy sweeping amongst coarse herbage with a probability of rose or bramble shoots, a bag of oatmeal cloth or unbleached calico upon a strong ring is required. The bag

should not be fastened to the ring by the latter being run through a heading, as the cloth will soon get worn through by the constant rubbing, and it should be fastened beneath the ring, which may be a flat band of metal with holes pierced through one edge of the band, or the bag may be sown on to small rings which slide on an ordinary metal ring. Such a sweeping net should have a diameter of 16 or 18 inches, and, therefore, a considerable strain is likely to be put upon the ring unless steps are taken to avoid this. If the handle is run right across the ring, it will give the necessary support.

A very convenient folding sweeping net is obtainable from the dealers, the ring being made of spring metal, and the whole structure is strong and much less weighty than where a stiff metal ring is used.

Sweeping merely consists in dragging the net backwards and forwards through the vegetation by the swing of the arm, and by this means insects are knocked off the plants into the net.

There are many insects to be obtained by

sweeping at night which rarely appear in the net during the day. Calm weather or a sheltered spot naturally will give the best results.

Beating is either done into an inverted umbrella or into a special beating tray obtainable from any of the dealers. The latter has a wider spread than the former, but the umbrella can be used for its usual purpose in the event of rain. A white lining is perhaps better than a black one for seeing the insects, but each collector must settle that point for himself. The umbrella or tray is held beneath a bush or a branch of a tree and the leafage is shaken, either by hand or by beating with a stick. Do not beat so violently that you cause great pieces of the plant to break off; it is not necessary, and, should you be operating upon some one else's trees, you will not be encouraged to continue. Very gentle beating is all that is required, and, as most of the insects will be dislodged by the first blow, there is no need to continue hammering for more than a few seconds.

If the weather is bright, many of the winged

insects which fall will quickly take flight, so that frequent examinations of the contents are advisable, and, where possible, make the examination in the shade, even if it is only in the shadow of your own body Trees inside woods, unless standing in open clearings, seem to produce less than those on the edges, but one may perhaps get species in the thicker parts which do not occur elsewhere.

The collector should always carry with him either a large sheet of thick paper or preferably a sheet of waterproof material. The advantages of the latter are obvious, as it can be used for sitting or for kneeling upon when not otherwise required. Its main purpose, however, is for the examination of moss torn off stones or the bark of trees, flood refuse, and all sorts of litter which can be shaken out over it. Collecting from stack-refuse, the loose material lying around the base of a haystack, or from decaying vegetation lying beneath trees in a wood, can be carried on during the winter months when many other forms of collecting are impossible. The refuse

can be gathered up in the hands and shaken over the sheet or worked through a small coarse sieve. This material yields many kinds of insects, but mostly beetles and bugs.

Flood refuse is very remunerative, but everything depends upon gathering the material at the psychological moment. When the streams rise and flood the adjoining land, they cause leaves, bits of grass, twigs, etc., to float up, and to these the drowning insect population clings. The refuse sooner or later gets thrown up on the edges of the flood, and it then provides the best harvest, because the insects quickly disperse when they once more find themselves on land. But flood refuse will give good results for some time after its deposition, larger masses naturally retaining insects longer than smaller ones, and many insects have been recorded from this sort of material long before they were known anywhere else.

Flood- and stack-refuse can, of course, be gathered into a bag and taken home for subsequent examination, but, whenever possible,

the collector should work in the field. One is apt to find a single specimen of some special treasure when one examines the material at home, whereas, if the discovery had been made on the spot, a full series might have been taken by continued working. The resolution to go and collect carefully the next time a flood occurs is quite likely to result in disappointment; most of us with experience have suffered from not taking a thing at the time it is abundant, in the belief that, as it is so common to-day, it will be equally common to-morrow.

The waterproof sheet is also useful for other purposes. Tufts of grass can be shaken out over it; carcases of animals and dried dung may be broken up and examined on it. A mole's nest or a disused bird's nest, gathered up and shaken over it, will yield all sorts of insects which were regarded as very rare before these kinds of material were examined. Fungi, either off trees or growing on the ground, can be gathered and broken up, and bits of decaying wood and bark can be similarly

treated, and all these materials provide their own insect fauna.

In collecting, the naturalist would be well advised to take all the larvæ he finds with adult insects, as there is an immense amount of work to be done upon these. The majority of life-histories are still unknown, and our knowledge of the larvæ of many forms depends upon the finding of them associated with a particular species of imago. Although this is not a reliable method, it becomes more accurate with the frequent repetition of the same association. Such collected larvæ should be placed at once in small tubes of alcohol (70 per cent.), either with some specimens of the imagines found with them or with a numbered label, referring to a note as to the conditions under which they were found and the adults which were with them.

A method of collecting which often yields good results, mainly perhaps to the beetle- or ant-collector, is the turning over of large stones, under which various species may be found. It seems, however, as if some of the

most exciting methods of collecting, at least in temperate climates, are more for the moth-collector than for anyone else, and amongst these are what may be described shortly as " light " and " sugaring."

" Light " is making use of the fact that many night-flying insects, especially moths, are attracted to light, and this can be done in two or three ways. A light placed inside a room near an open window will attract moths and some other insects into the room, where they may be chased with a butterfly net, often with disastrous results to ornaments and pictures. In the tropics, many other insects are attracted to light, and one experiences the doubtful pleasure of " white ants," large cockroaches, and other unpleasant insects, falling into the soup-plate at dinner time.

A lantern set up on the outskirts of a wood or in a clearing, and so placed that the light falls upon a white sheet set up vertically, will often yield a good harvest, as the moths settle on the sheet in the rays of light and can be boxed quite easily. Even carrying a lantern

and a net in such situations enables the collector to catch many specimens as they fly across the path of the light, and collecting in the rays of the headlights of a motor car, drawn into a quiet lane by a wood, is most entertaining.

But the attraction of light varies greatly, one night producing a large number of specimens, another yielding next to nothing. This, no doubt, is dependent in some way on the weather, but it is not yet known just what the determining factors are. As a rule, the ideal night is cloudy and warm and calm, with a thundery atmosphere and occasional large drops of rain. On the other hand, a clear moonlight night is generally useless. And yet everyone experiences strange exceptions : ideal nights yielding nothing and cold moonlight nights on which the whole moth population seems to be on the move.

The insects which are attracted by light are those which are out either in search of a mate or of food, and therefore an examination of flower-heads, with the aid of a lantern, is a

valuable method of collecting. No doubt the attractiveness of many flowers varies under different conditions, but certain flowers seem to be specially attractive almost everywhere—for instance, honeysuckle. A privet hedge in full bloom, although its scent is not appreciated by many collectors, is a very effective attraction for moths, while valerian, verbena, and various other flowers, especially when in masses, are well worth a scrutiny. In the spring, sallow, and in the autumn, ivy-blossom, are noted for the species which frequent them.

But it is not always easy to collect the insects sucking the nectar from flowers at night, as on some, such as honeysuckle, they do not settle down, and to dash the net hastily across a cluster of flowers may perhaps result in the capture of the specimen, but will almost certainly damage the flowers and interfere with their attractiveness. In the case of ivy-blossom and many other kinds where a mass of small flowers forms a large head, the insect has to settle down, as it draws a little

nectar from each of the flowers in the head, and therefore it becomes a fairly easy matter to enclose it in a pill-box while it feeds. The light should be brought to bear upon the flower-head, and the capture should, of course, be made quickly and as quietly as possible.

Just as the nectar of flowers is attractive to insects, so also is the sugary fluid excreted by aphides, and this often covers the vegetation with a sticky varnish. This "honey-dew" attracts insects by the score during the day, when many kinds of wasps, bees, flies, and other insects may be found crawling over the leaves and licking it up. Similarly at night it attracts the moths and other insects, so that a good honey-dew night will provide a lot of material for the collector.

"Sugaring" consists of providing an attractive fluid as a bait, and, just as the flowers mostly advertise the presence of the nectar by emitting a scent, so to the sugar it is usual to add some aromatic. There are many formulæ for making up a suitable material, some of which require "old beer," whatever that may

be, but the essential point is to produce something sweet, aromatic, and sufficiently thick to remain on a vertical tree trunk, post, or paling, when painted on.

Brown sugar and beer boiled to a consistency of treacle, or, more simply, brown sugar and treacle mixed together and thinned, if necessary, with a little beer, form a good basis. The addition of a little rum, about a tablespoonful to a pint, and of a small, *a very small*, amount of an aromatic, such as essence of lemon, aniseed, or jargonelle pear, immediately before application, completes the "sugar." The material is usually carried in a painter's can, and painted, preferably in narrow vertical streaks, on the sheltered side of the tree or fence, just about dusk. A number of trees should be painted, so that the collector may make a continuous round of visits during the evening. The edges of a wood or open spaces in a wood are the best for sugaring, and the remarks made about weather conditions in connection with light apply equally here.

Pupa-digging is a winter occupation of the

moth-collector, although it may be carried on from August to April with good results. The only instruments necessary are a trowel, with which to dig at the roots of trees, and a box containing moss for carrying the pupæ. Trees at the edges of woods or in clearings, or, best of all, isolated trees in park-land or meadows, yield the best results, and the side facing the north is usually more productive than that facing south, presumably because the caterpillar knows that there is less risk of excessive heat or drought on the north side.

Here, again, the waterproof sheet comes into use. The trowel is inserted under the soil or tuft of grass against the base of the tree, or, better, in an angle between two projecting roots, and the material so lifted is shaken over the sheet. Moss on the base of the trunk is gathered and treated in the same way. The method requires considerable patience, and is more apt to provide a number of specimens of a few, usually common, species rather than great variety or rareties.

Water insects attract many collectors, and

it is surprising to see what utterly inefficient nets many of them use. Water nets, made of the usual cheese-cloth, have a very short life, and usually seem to come to a sudden end in the middle of a day's collecting. The ring used is often much too weak, so that it either bends as it is being worked in the water or breaks off where it is joined to the handle. After a long and painful apprenticeship, a really efficient instrument was devised a numbers of years ago, and was first made by Messrs. Patterson & Sons, Ironmongers, High Street, Belfast. The pattern is still used by the members of the Belfast Naturalists' Field Club, where it is known as the "Balfour-Browne Water Net," and it is now obtainable from Messrs. Watkins & Doncaster, 36, Strand, London, W.C. 2. The efficiency of a water net depends upon the ease and rapidity with which the water passes through the meshes. If these are too small—and many materials when wet swell up—the water in the bag merely forms a solid wall and pushes away other water and the insects it contains, as the net is pushed

along. The best material of all for the bag is a wide-meshed bolting-silk, but, as each bag costs about ten shillings in mere material, and as it does not last very long, few collectors will care to use it. Mosquito netting is much cheaper, and wears fairly well, while a type of linen canvas will wear better, but is rather less efficient. The ring should be 11 or 12 inches in diameter, though for working narrow ditches and small holes an 8-inch ring is useful.

But the failure of many water-insect collectors lies in their method of using the net. Few insects are to be found in the mud at the bottom of a pond or stream, and yet the net is usually brought up half full of this, and, once the insects become mixed up with it, they are very hard to discover. The correct method is to work the net backwards and forwards fairly rapidly, without touching the bottom. This will cause the water to swirl and will draw up any insects resting on the bottom, and these will be captured on the return movement of the net. The net should come up without any mud, and, if the contents are emptied on to

the waterproof sheet, the insects will soon move out of any debris and make themselves visible.

In all kinds of collecting there is a natural tendency on the part of the collector, relying upon previous experience, to form an opinion as to whether a particular spot is worth investigation, and this is unfortunate, because the impression is often wrong. On an expedition some years ago, one of the party, an old and experienced collector, was given to expressing his opinion as to collecting grounds, and a younger man, with a turn for humour, played a trick upon him which he repeated several times. Having got the expert to declare the complete uselessness of a particular spot, the young man worked the ground, and, a little later, took his captures to the older man. The latter, after examining the material, remarked, "You have got some good things here; where on earth did you get them?" "On the bit of ground which you said was no use," replied the young man.

The most unpromising muddy pond, or some

bare strip of land, frequently yields good results, so that the collector should, on principle, examine such " useless " places.

A few instruments of the chase have already been referred to, but several others should be mentioned. A cold chisel or even an axe come in very useful in stripping the bark off a dead tree or breaking up rotten wood. If any attempt is to be made to rear any of the larvæ, mostly of beetles and flies, which occur in such situations, it will be necessary to transport some of the material, and it is therefore useful to carry a few bags, about 20 × 15 inches, made of unbleached calico.

Many collectors take home their captures alive, and, as this usually necessitates each specimen having a place to itself, it means the transport of a number of boxes or glass tubes, according to the nature of the material.

The Lepidopterist mostly uses pill-boxes, preferably with a glass bottom—not top—but a cheaper chip box can be substituted. Collectors of Hymenoptera and of bugs and others also frequently prefer these boxes, and they can

be bought in "nests," which consist of five or six boxes one inside the other.

The Coleopterist usually prefers glass tubes and tin boxes for his captures, and there are excellent metal boxes to be bought containing glass tubes, each in a separate compartment. These boxes contain either six tubes 3×1 inches, or twenty-six tubes $1\frac{3}{4} \times \frac{3}{8}$ inches, and there are others containing tubes between these sizes. It is not advisable to carry tubes loose in the pocket, as corks are apt to come out. For specimens too large for the largest tubes, two- and four-ounce tobacco-tins are very useful.

It is, however, often convenient to kill specimens in the field, and for this purpose potassium cyanide is very commonly used. A small piece, wrapped in paper, and pushed to the bottom of a glass tube, is suitable for small specimens, and the usual large-mouthed bottle containing cyanide pieces covered with a layer of plaster of Paris suffices for larger ones. It is, however, unwise to allow large specimens to roll about in the bottle, and, if this method is

used, the specimens should, after ten or fifteen minutes, be transferred to some other container. They can be pinned into a store box or wrapped in tissue paper and stored in a tube or in a box of sawdust. A very efficient material for killing insects is bruised laurel leaves. Leaves taken from the common green laurel—not the aucuba—are cut into narrow strips with a pair of scissors, and the strips are then chopped up. A mass of this chopped material is then wrapped up in a piece of muslin or thin calico, and this is pushed to the bottom of a glass tube. Such a tube will last for some months, and it has the advantage over the cyanide tube that specimens can be left in it a long time and remain relaxed. In one case, specimens brought home in one of these tubes from Brazil in August 1923 were still pliable and fit for setting in November 1925.

A wide-mouthed bottle with bruised laurel leaves occupying about one-third of it, and with a layer of plaster of Paris over them, make a very good substitute for the large cyanide bottle.

For killing specimens after they have been brought home, there are other methods beside cyanide and laurel leaves. For killing beetles and leaving them in a relaxed condition, suitable for mounting, there is nothing better than hot water, but the water must be just off the boil. Putting them into boiling water is likely to stiffen them, and, in the same way, if the water is not quite hot enough, they will not be very easy to set. They should not be left in the water more than half a minute, and should then be lifted out, laid upon blotting-paper, and mounted as soon as possible. Even with long experience, one frequently does not get the insects in the most perfectly relaxed condition by this method, but they are always capable of being set if the setting is done at once. Cyanide- and laurel-killed specimens are best left twenty-four hours in the killing-bottle before any attempt is made to set them, as they die stiff and then gradually relax.

Most Hymenopterists will say that a bee or a wasp is ruined if it is wetted, so that boiling

water is not regarded as suitable for killing them. And yet one authority, quoted in a charming little book, "The Insect Hunter's Companion," (28) which first appeared before 1870, has passed through many editions, and is still obtainable, says that they can be dropped into boiling water, which has the advantage of killing them, in nine cases out of ten, with the wings expanded and the legs stretched out. They must, almost immediately, be lifted out on a camel's-hair brush and placed in cold water. Each insect must then be immersed in 90 per cent. alcohol and lifted out on a glass slide, the insect being on its back. The legs, wings, and antennæ are brushed out and excess spirit is mopped up with blotting-paper, and the insect is then allowed to dry, which it does in a few minutes.

Ethyl acetate (acetic ether) is useful for killing these insects, because it causes them to die with their mouth-parts fully extended and the wings and legs relaxed. Care should, however, be taken to prevent too free an escape

of the vapour, as it has a bad effect upon human beings as well as insects.

The collector should always carry a pocket lens of low magnification (× 8), but a higher power (× 15 or × 20) is also often very useful. Also a fine pair of forceps is a *sine quâ non*, but a word should be said with regard to these. The forceps which one buys are stiff and require very careful handling if a delicate insect is to be lifted with them, and it is advisable to carry a second pair, which is easily made at home, if the necessary material is still to be obtained. The changes in female fashions have caused the disappearance of the old-fashioned corsets, which to some extent at least relied for their stiffness upon steel "ribs." These were long strips of springy steel, ½ inch and less in width. Over the flame of a spirit lamp, heat one of these ribs about 5 or 6 inches from the end, and, when it is red hot, bend the short end so that it comes to lie flat upon the longer one. Now cut off the projecting portion of the longer piece, so that the two parts left are equal in length. Once more heat this double piece

about $\frac{1}{2}$ inch from the double end, and, when it is sufficiently hot, bend out the two pieces so that they are about $\frac{3}{8}$ inch apart at the ends. Then plunge into cold water. The instrument is now completed by filing, and it should be placed in a vice for this purpose, the two free ends being jammed together so that both are filed at the same time. They must be brought to a common point, either at the extremity, or, by filing out a portion of one of the sides, the points can be curved. In this way a pair of very light spring forceps is made, which is always coming in useful, and even delicate insects can be picked up without damage.

It would, of course, be possible for a whole chapter to be written upon methods of collecting one group of insects, as there are various special methods for all possible contingencies, but we have here only endeavoured to give a few more or less general instructions, in order to enable the novice, who may have become interested in insects through reading the previous chapters, to try his hand at collecting.

As a final word of advice to the novice, he should remember that he spends a large part of his time trespassing on other people's property, and he must therefore be considerate. The man who leaves gates open, breaks down fences, rips bark off living trees, and does other kinds of damage is not only likely to make himself unpopular with owners and keepers, but is spoiling the field for other workers. It is extraordinary what freedom is permitted to the entomologist if he shows consideration and is patient and courteous when he is examined as to what he is doing.

The importance of the study of entomology has at last come to be recognised, owing to the immense damage done by insects to our crops, our cattle, and even to ourselves. Whereas the subject used to be scarcely touched upon in Zoological Courses at the Universities, it is now given more adequate treatment, and there are special courses given at Cambridge and at the Imperial College of Science, London, for the training of men wishing to take up economic work.

Any one who is really interested in entomology can now study it with a view to making it his life's work, and the Colonies are employing more and more men trained in Agricultural Entomology. Recently also a new field of work has been developing, as the various commercial interests are coming to realise what can be saved by checking the damage done by insects to the various stored animal and vegetable materials. At present, the large losses caused to various stored products are passed on to the consumer, so that we pay for what the insects destroy; but one or two of the trades are getting interested in the subject, and have already taken the advice of entomologists as to methods of reducing these losses. It is probable, therefore, that, in the near future, Industrial Entomology will be another well-recognised line of work—in fact, the entomologist who, until recently, was looked upon as a harmless lunatic is about to come into his own.

BIBLIOGRAPHY

1. Balfour-Browne, F.: "Evolution of Social Life among Caterpillars." Verhandlungen des III Internationalen Entomologen-Kongresses. Zurich, 1925, pp. 334–340.
2. Carpenter, G. H.: "Insects, their Structure and Life." Dent & Sons. Second Edition. 1924.
3. —— "The Life-story of Insects." Cambridge Manuals of Science and Literature. Camb. Univ. Press, 1913.
4. Darwin, C.: "The Formation of Vegetable Mould through the Action of Worms." John Murray, 1892.
5. Fabre, J. H.: "Souvenirs Entomologiques" (parts). English Translation. "The Glow-worm and other Beetles." Hodder & Stoughton.
6. —— "Souvenirs Entomologiques" (parts). English Translation. "The Sacred Beetle and Others." Hodder & Stoughton.
7. —— "Souvenirs Entomologiques" (parts). English Translation. "The Hunting Wasps" (Chap. xvii). Hodder & Stoughton.
8. Froggatt, W. W.: *Agricultural Gazette, New South Wales*, 1901, pp. 1–11.
9. Goldschmidt, R.: "The Mechanism and Physiology of Sex Determination." English Translation by Prof. W. J. Dakin. Methuen, 1923.
10. Harrison, J. W. Heslop: "The Induction of Melanism in the Lepidoptera and its subsequent inheritance." Proc. Roy. Soc., B, Vol. 99, 1926, pp. 241–263.
11. Haviland, Miss M. D.: "On the Post. Embryonic Development of certain Chalcids, Hyperparasites of Aphides, with Remarks on the Bionomics of Hymenopterous Parasites in General," *Quart. Journ. Micr. Science*, Vol. 66, 1922, pp. 321–338.

12. Imms, A. D. : "Textbook of Entomology." Methuen, 1925.
13. —— "The Biological Control of Insect Pests and Injurious Plants in the Hawaiian Islands." *Annals of Applied Biology,* Vol. XIII, 1926, pp. 402–422.
14. Imms, A. D., and N. C. Chatterjee : "On the Structure and Biology of *Tachardia lacca,* Kerr [The Lac-Insect]," *Indian Forest Memoirs,* Forest Zoology Series III, Calcutta, 1915.
15. Johnson, H. B. : "A further Contribution to our Knowledge of the Bionomics and Control of the Migratory Locust, *Schistocerca gregaria,* Forsk. (*peregrina,* Oliv.) in the Sudan," *Sudan Govt. Ent. Section Bulletin,* No. 22, June 1926.
16. Latter, O. H. : "Bees and Wasps." Cambridge Manuals of Science and Literature. Camb. Univ. Press, 1913.
17. L'Arbousset : "On Silk and the Silkworm." Translated by R. A. Wardle. W. H. Eaton, Leek, 1905.
18. Lefroy, H. M. : "Silk Production in the Empire," *Bulletin Imperial Institute,* Vol. XXII, 1924, pp. 152–171.
19. Marchal, P. : "Recherches sur le développement des Hyménoptères Parasites. I. La Polyembryonie spécifique ou germinogonia," *Arch. Zool. Exper.,* T. ii., 1904, pp. 257–335. II. "Les Platygasters," *ibid.*, 1906, pp. 485–639.
20. Maeterlinck, M. : "The Life of the Bee." Translated by Alfred Sutro. Geo. Allen & Unwin, Ltd., 1901.
21. Pictet, A. : "La proportion des sexes dans les espèces sexuées et les espèces parthénogénétiques." Verhandl. des III Internationalen Entomologen-Kongresses, 1925, pp. 305–322.
22. Sambon, L. W. : "Observations on the Life-history of *Dermatobia hominis,*" *Rept. of the Advisory Committee for the Tropical Diseases Research Fund for the year* 1914, Appendix VII, pp. 119–150. H.M. Stationery Office, 1915.
23. Shinji, G. O. : "A Contribution to the Physiology of Wing-development in Aphids," *Biol. Bull.*; *Marine Biol. Lab.,* Woods Hole, Mass., Vol. XXXV, 1918, pp. 95–116.

24. Smith, G., and H. A. Hamm: "Studies in the Experimental Analysis of Sex. Part II. On Stylops and Stylopisation," *Quart. Journ. Micr. Science*, 60, 1914.
25. Tickner Edwards: "The Lore of the Honey-bee." Methuen, 1911.
26. Wheeler, W. M.: "The Parasitic Aculeata: A Study in Evolution," *Proc. Amer. Phil. Soc.*, Vol. LVII, 1919.
27. —— "Social Life among the Insects." Constable & Co., 1922.
28. "The Insect Hunter's Companion." Adlard & Son, 6th Edition, 1924.

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